ALLIED ENVIRONMENTAL CONDITIONS AND TEST PUBLICATION

AECTP 400

MECHANICAL ENVIRONMENTAL TESTS

COVERING STANAG 4370

2000

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AECTP 400 is one of five documents included in STANAG 4370. It is important for users to note that the content of AECTP 400 is not intended to be used in isolation, but is developed to be used in conjunction with the other four AECTPs to apply the Environmental Project Tailoring process. This process insures that materiel is designed, developed and tested to requirements that are directly derived from the anticipated Service use conditions. It is particularly important that AECTP 400 is used in conjunction with AECTP 100 which addresses strategy, planning and implementation of environmental tasks, and AECTP 200 which provides information on the characteristics of environments and guidelines on the selection of test methods.

The test methods contained herein together with associated assessments are believed to provide the basis for a reasonable verification of the materiel's resistance to the effects of the specific mechanical environments. However, it should be noted that the test methods are intended to reproduce the effects of relevant environments and do not necessarily duplicate the actual environmental conditions. Where possible, guidance on the limitations of the intended applications is provided. The use of measured data for the generation of test severities is recommended if available.

AECTP 400 Test Methods address mechanical environments, both individually and when combined with other environments, such as climatic environments included in AECTP 300. The application of combined environments is relevant and often necessary where failures could be expected from potential synergistic effects.
In developing a test programme, consideration is to be given to the anticipated life cycle of the materiel and to the changes in resistance of the materiel caused by the long term exposure to the various mechanical environments. The environmental conditions included by the appropriate materiel platforms are also to be accommodated. Guidance on these aspects and information on the characteristics of environments is provided in AECTP 200. Guidelines for the planning and implementation of environmental tasks is given in AECTP 100.

AECTP 400 was not developed specifically to cover the following applications, but in some cases they may be applied :

a. weapon effects, other than EMP,
b. munitions safety tests covering abnormal environments,
c. packaging testing,
d. suitability of clothing or fabric items intended for military use,
e. environmental stress screening (ESS) methods and procedures.

The enclosed list of AECTP 400 Test Methods reflects those currently developed and completed. It is not comprehensive in that it will be revised as other methods are developed. All the methods listed are not to be applied indiscriminately, but rather selected for application as required.

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VIBRATION

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GUIDANCE FOR EXTERNAL TEST SEVERITIES

METHOD 401

VIBRATION

1 SCOPE

1.1 Purpose

The purpose of this test method is to replicate the effects of the vibration environments incurred by systems, subsystems and units, (hereafter called materiel) during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified vibration environment without unacceptable degradation, of its functional and/or structural performance.

AECTPs 100 and 200 provide additional guidance on the selection of a test procedure for a specific vibration environment.

1.3 Limitations

It may not be possible to simulate some actual operational service vibration environments because fixture limitations or physical constraints may prevent the satisfactory application of the vibration excitation to the test item.

2 GUIDANCE

2.1 Effects of environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to a vibration environment.

(1) Wire chafing

(2) Loosening of fasteners

(3) Intermittent electrical contacts.

(4) Mutual contact and short circuiting of electrical components

(5) Seal deformation.

(6) Structural and component fatigue.

(7) Optical misalignment.

(8) Cracking and rupturing.

(9 Loosening of particles or parts that may become lodged in circuits or mechanisms.

(10) Excessive electrical noise.

2.2 Use of Measured Data

Where practicable, field data should be used to develop test levels. It is particularly important to use field data where a precise simulation is the goal. Sufficient field data should be obtained to describe adequately the conditions being evaluated and experienced by the materiel.

2.3 Sequence

The effects of vibration may affect performance when materiel is tested under other environmental conditions, such as temperature, humidity, pressure, electromagnetic, etc.

Also, it should be noted that it is essential that materiel which is likely to be sensitive to a combination of environments is tested to the relevant combinations simultaneously.

Where it is considered that a combined test is not essential or impracticable to configure, and where it is required to evaluate the effects of vibration together with other environments, a single test item should be exposed to all relevant environmental conditions in turn.

The order of application of tests should be considered and made compatible with the Service Life Environmental Profiles. If any doubts remain as to the order of testing, then any vibration testing should be undertaken first.

2.4 Choice of test procedures

The choice of test procedure is governed by many factors including the in-service vibration environment and materiel type. These and other factors are dealt with the General Requirements - AECTP 100 and in the Definition of Environments - AECTP 200

This test method contains four procedures. They are:

Procedure 1 : swept frequency sinusoidal vibration

Procedure 2 : fixed frequency sinusoidal vibration

Procedure 3 : random vibration

Procedure 4 : random vibration (stores)

Table 1 provides a test procedure selection matrix as a function of platform and type of environment.

Materiel may be exposed to more than one vibration environment. For example, materiel installed in aircraft will be subjected to both the transportation environment as well as the aircraft induced environment. In such cases the materiel may be required to be tested to more than one procedure.

2.5 Types of vibrations

A brief description of each type of vibration that can be used in procedures 1 to 4 is given in the following paragraphs.

2.5.1 Swept frequency sinusoidal vibration

Swept frequency sinusoidal vibration consists of sinusoidal motion whose frequency is varied at a specified sweep rate, over a specified frequency range. The amplitude of the motion may also vary over the frequency range. This type of vibration has application in the representation of environments where the materiel experiences vibration primarily of a periodic nature. It may also have applications where fatigue is to be assessed.

A swept frequency sinusoidal vibration severity is defined by the following parameters :

- the amplitude/frequency profile,
- the sweep rate and type of sweep
- the duration of the test.

2.5.2 Fixed frequency sinusoidal vibration

Fixed frequency sinusoidal vibration has application to a range of materiel subjected to fixed and known frequencies. It may also have application to the rapid accumulation of stress reversals in order to assess the effects of fatigue.

A fixed frequency sinusoidal vibration severity is defined by the following parameters :

- the amplitude(s) of vibration,
- the frequency of the sinusoid(s),
- the duration of the test.

2.5.3 Wide band random vibration

Wide band random vibration exhibits instantaneous level with a nominally gaussian distribution in the time domain. The spectrum levels may be constant or shaped over a broad frequency range. These conditions are likely to be experienced by most materiel at some time in their service life.

A wide band random vibration severity is defined by the following parameters :

- the Acceleration Spectral Density (ASD) spectrum profile,
- the test frequency range,
- the root mean square (rms.) level over the test frequency range
- the duration of test

2.5.4 Fixed Frequency Narrow Band Random Vibration

Fixed frequency narrow band random vibration has its spectral amplitude constrained within a narrow frequency range. It may be used to represent vibration which is periodic but not necessarily sinusoidal.

A narrow band random vibration severity is defined by the following parameters :

- the ASD spectrum profile,
- the test frequency range,
- the rms. Level over the frequency range,
- the duration of the test,

2.5.5 Swept narrow band random vibration

Swept narrow band random vibration is defined as a narrow band of random vibration that is swept over a specified frequency range.

A swept narrow band random vibration severity is defined by the following parameters:

- the ASD spectrum profile of the narrow band,
- the swept frequency range,
- the rms. level of the narrow band,
- the sweep rate and type of sweep

- the duration of test.

2.5.6 Fixed frequency sinusoidal vibration on wide band random vibration

Fixed frequency sinusoidal vibration on wide band random vibration is defined as one or more fixed frequency sinusoids superimposed on wide band random vibration. Where several host platforms are specified swept frequency sinusoidal vibration, or swept frequency narrow band random vibration, on wide band vibration may be more representative.

A composite vibration severity consisting of fixed frequency sinusoidal component(s) on a wide band random vibration background is defined by the following parameters :

- the ASD spectrum profile of the wide band random vibration,
- the test frequency range of wide band random vibration
- the rms. level of the wide band random spectrum over the test frequency range,
- the amplitude(s) of the sinusoid(s),
- the frequency of the sinusoid(s),
- the duration of the test.

Type	PURPOSE			DESCRIPTION	PROCEDURES
TRANSPORT	Basic transport as secured cargo			Materiel carried out as secured cargo. Air, Sea and Ground	3 or 3 & 1
	Propeller Aircraft			Materiel installed in propeller aircraft	3 or 3 & 2
	Jet Aircraft			Materiel installed in jet aircraft	3
	Helicopter			Materiel installed in helicopter	3 or 3 & 2
	Ground mobile			Materiel installed in ground vehicle	3
	Shipboard			Materiel installed in ship	3 or 3 & 2
	Missiles			Materiel installed in missile	3
	EXTERNAL STORES	CAPTIVE FLIGHT	Propeller aircraft	Assembled stores Materiel installed in stores	4 3
			Jet Aircraft	Assembled stores Materiel installed in stores	4 3
			Helicopter	Assembled stores Materiel installed in stores	4 3
			Ground mobile	Assembled stores Materiel installed in stores	4 3
			Ships	Assembled stores Materiel installed in stores	4 & 1 1 & 3
		Free flight		Assembled stores Materiel installed in stores	4 3
Integrity		Minimum requirement		Materiel off isolator	3
Development		Design tool		Initial testing of prototype or new materiel for providing design information	1 or 2 or 3

TABLE 1 - TEST PROCEDURES SELECTION

2.5.7 Swept frequency sinusoidal vibration on wide band random vibration

Swept frequency sinusoidal vibration on wide band random vibration is defined as one or more sinusoids swept over a frequency range, and superimposed on random vibration.

A composite vibration severity, consisting of swept frequency sinusoidal component(s) on a random vibration background, is defined by the following parameters :

- the ASD spectrum profile of the wide band random vibration,
- the test frequency range of the wide band random vibration,
- the rms. level of the wide band random vibration over the test frequency range,
- the amplitude(s)/frequency profile(s) of the sinusoids,
- the sweep rate and type of sweep
- the duration of the test.

2.5.8 Fixed frequency narrow band random vibration on wide band random vibration

Fixed frequency narrow band random vibration on wide band random vibration is defined as one or more narrow bands of random vibration superimposed on wide band random vibration. This type of vibration is essentially the same as the wide band random vibration application described earlier.

A composite vibration severity of fixed centre frequency narrow band random component(s) superimposed on a wide band random vibration background is defined by the following parameters

- the ASD spectrum profile of the wide band random vibration,
- the test frequency range,
- the ASD spectrum profile, of the narrow band random vibration,
- the rms. level over the test frequency range,
- the duration of the test.

2.5.9 Swept frequency narrow band random vibration on wide band random vibration

Swept frequency narrow band random vibration on wide band random vibration is defined as one or more narrow bands of random vibration swept over a frequency range and superimposed on a background of wide band random vibration.

A composite vibration severity of swept narrow band random vibration superimposed on a wide band random vibration background is defined by the following parameters :

- the ASD spectrum profile on the wide band random vibration,
- the test frequency range,
- the ASD spectrum profile(s) of the narrow band random vibration,
- the swept frequency range,
- the sweep rate and type of sweep

– the rms. level over the test frequency range,

– the duration of the test.

2.6 Control Strategy and Options

2.6.1 Strategy

The vibration excitation is controlled to within specified bounds by sampling the vibratory motion of the test item at specific locations. These locations may be at, or in close proximity to, the test item fixing points (controlled input tests) or at defined points on the test item (controlled response tests). The vibratory motions may be sampled at a single point (single point control), or at several locations (multi-points control).

The control strategy will be specified in the Test Instructions. However, it should be noted that it could be influenced by :

– the results of preliminary vibration surveys carried out on materiel and fixtur es,

– meeting the test specifications within the tolerances of 5.1.,

– the capability of the test facility.

In view of the possibility of frequency drift, it is essential when conducting fixed frequency sinusoidal "resonance dwell" tests that the frequency be constantly adjusted to ensure a maximum response. Two method are available :

– search for the maximum dynamic response,

– maintain the phase between the control and monitoring points.

2.6.2 Single point control option

This option can be used when the preliminary vibration survey shows that inputs to the test item are normally equal at each fixing point or when one control accelerometer accurately represents an average of the inputs at each fixing point. A single control point is selected :

– either from amongst the fixing points,

– or from amongst the significant points of the test items's response

– or in such a way that it provides the best possible solution for achieving the tolerances at the fixing points.

2.6.3 Multiple points control (average) option

The option can be used when the preliminary vibration survey shows that inputs to the test item vary significantly between fixing points. The control points, usually two or three, will be selected using the same criteria listed in par. 2.6.2. for the single control point option. However, the control for :

– random : will be based on the average of the ASD's of the control points selected.

– sine : will be based on the average of the peak response values at the control points selected

2.6.4 Multiple points control (maximum) option

This option can be used when responses are not to exceed given values, but care is needed to avoid an undertest. Preliminary vibration survey results are used to aid the definition of the control points on the test item at which maximum response motions occur. The control points, usually two or three, will be selected using the same criteria listed in para. 2.6.2. for the single point option. However, the control for:

- random : will be based on the maximum spectrum response at any of the selected control points,
- sine : will be based on the maximum peak response at any of the selected control points.

2.7 Materiel operation

The test item should be operated and its performance measured and noted as specified in the Test Instruction or relevant specification.

3 SEVERITIES

3.1 General

When practicable, tests levels and durations will be established using projected service use profiles and other relevant available data. When data are not available, initial test severities are to be found in Annex A ; these severities should be used in conjunction with the appropriate information given in AECTP 200. These severities should be considered as initial values until measured data is obtained. Where necessary these severities can be supplemented at a later stage by data acquired directly from an environmental measurement program.

3.2 Supporting assessment

It should be noted that the test selected may not be an adequate simulation of the complete environment and consequently, a supporting assessment may be necessary to complement the test results.

3.3 Isolation system

Materiel intended for use with vibration isolation systems should normally be tested with isolators in position. If it is not practicable to carry out the vibration test with the appropriate isolators, or if the dynamic characteristics of the materiel installation are very variable, for example temperature dependent, then the test item should be tested without isolators at a modified severity specified in the Test Instruction. In the case where a continuous vibration test can cause unrealistic heating of the test item and/or isolators, the excitation should be interrupted by periods of rest which should be specified in the Test Instruction.

3.4 Subsystems

When identifies, in the test plan, subsystems of the materiel may be tested separately. The sbsystems can be subjected to different vibration levels. In this case, the Test Instruction should stipulate the test levels specific to each subsystem.

4 INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- the identification of the test item,
- the definition of the test item
- the type of test : development, qualification, etc.,

- the orientation of the test item in relation to the test axes,
- if operating checks are to be performed and when,
- for initial and final checks, specify whether they are to be performed with the test item installed on the test facility,
- other relevant data required to perform the test and operating checks,
- the vibration control strategy
- the monitor and control points or a procedure to select these points,
- the pre-conditioning time,
- the use of isolator mounts or otherwise,
- the definition of the test severity,
- the indication of the failure criteria,
- the way of taking into account, tolerance excess in the case of large test item and a complex fixture,
- any other environmental conditions at which testing is to be carried out if other than standard laboratory conditions.

4.2 If required

- the specific features of the test assembly (vibrator, fixture, interface connections, etc.),
- the effect of gravity and the consequent precautions,
- the value of the tolerable spurious magnetic field,
- tolerances, if different from para. 5.1.

5 TEST CONDITIONS

5.1 Tolerances and Related Characteristics

5.1.1 Sinusoidal vibrations

The test facility should be able to excite the materiel in the way stipulated in the Test Instruction. In these conditions the motion should be sinusoidal and such that the fixing points of the test item move substantially in phase with and parallel to the excitation axis.

The sinusoidal tolerances and related characteristics defined in table 2 below (sinusoidal tolerances) should be used and checked with the test item installed. Only under exceptional circumstances should a Test Instruction need to specify different tolerances.

The complete test control system should not produce uncertainties exceeding one third of the tolerances listed in Table 2.

The tolerances associated with the test severity parameters are not to be used to overtest or undertest the test item.

If tolerances are not met, the difference observed be noted in the test report.

Parameter	Tolerance (note 1)
Critical frequencies	+/-0.05 Hz from zero to 0.5 Hz +/-10% from 0.5 Hz to 5 Hz +/-0.5 Hz from 5 Hz to 100 Hz +/-0.5% above 100 Hz
Characteristic frequencies of the test profile (see note 2)	+/-0.05 Hz from zero to 0.25 Hz +/-20% from 0.25 Hz to 5 Hz +/-1 Hz from 5 Hz to 50 Hz +/-2% above 50 Hz
Sweep rate (see Note 3)	+/-10%
Fundamental amplitude of the vibration (displacement, velocity, acceleration)	+/-15% at the control signal +/-25% at the fixing points up to 500 Hz +/-50% at the fixing points above 500 Hz
Difference between the unfiltered signal and filtered acceleration signal (see note 4)	+/-5% on the R.M.S values
Transverse movement on the fixing points	<50% of the movement for the specified axis up to 500 Hz <100% above 500 Hz (in special cases, eg. small equipment, transverse movement may be limited to 25% and 50% respectively
Duration of tests	+/-5%

TABLE 2 - SINUSOIDAL TOLERANCES

Note 1

Critical frequencies are frequencies at which

- test items malfunction and/or detrimental performance are exhibited due to the effects of vibrations
- mechanical resonances and other response effects, such as chatter, occur.

Note 2

Characteristic frequencies are :

- the frequency limits of the sweeping frequency range,
- the transition frequencies of the test profile.

Note 3

Unless otherwise specified the vibration should be continuous and change exponentially with time at one octave per minute.

Note 4

A signal tolerance of 5% corresponds to a distortion of 32% by utilisation of the formula :

$$d = \frac{\sqrt{a_{tot}^2 - a_1^2}}{a_1} x100$$

where: - a_1 = rms. value of acceleration at the driving frequency,

- a_{tot} =total rms. of the applied acceleration (including the value of a_1)

5.1.2 Random Vibration

The test facility should be capable of exciting the test item to the random vibration conditions specified in the Test Instruction. The motion induced by the random vibration should be such that the fixing points of the test item move substantially parallel to the axis of excitation. In these conditions the amplitudes of motion should exhibit a normal distribution. The tolerances defined in table 3 below should be used and checked with the test item installed.

Since the control loop time depends on the number of degrees of freedom and on the analysis and overall bandwidths, it is important to select these parameters so that test tolerances and control accuracy can be achieved. When possible, identical analysis bandwidth should be used for both control and monitoring. When this is not possible due allowance should be made to the results of the monitoring analysis.

For swept narrow band random tests the tolerances on the swept components of the test requirement should wherever possible be the same as for wide band random component. However, at some sweep rates, these tolerances may not be achievable. Therefore, the tolerance requirements for these components shall be stated in the Test Instruction. The complete test control system including checking, servoing, recording, etc. should not produce uncertainties exceeding one third of the tolerances listed in Table 3

The tolerances associated with the test severity parameters are not to be used to overtest or undertest the test item.

If tolerances are not met, the difference observed should be noted in the test report.

PARAMETERS	TOLERANCES
Number (n) of independent statistical degrees of freedom (DOF) for control of the specified ASD RMS value of amplitude measured at the control point in the test axis	n > 100 +/- 10% of the preset RMS value
Maximum local amplitude deviation of the control ASD in relation to the specified ASD	+/- 3 dB above 500 Hz, locally (limited to 5% of the frequency range): +/- 6 dB
Maximum variation of the RMS value at the fixing points in the test axis	+/- 25% of the preset RMS value
ASD measured with the same number of DOF as in the test axis, along the two transverse directions.	Less than 100% of the specified ASD of the control point.
Amplitude distribution of the instantaneous values of the random vibration measured at the control point	Nominally Gaussian (see note 1)
Frequency sweep rate (see note 2)	+/- 10%
Test duration	+/- 5%

TABLE 3 – RANDOM TOLERANCES

Note 1

The distribution should contain all occurrences up to 2.7 standard deviation whilst occurrences greater than 3 standard deviations should be kept to a minimum.

Only under exceptional circumstances should a Test Instruction need to specify different tolerances.

Note 2

Unless otherwise specified, the vibration should be continuos and change exponentially with time at one octave per minute.

5.1.3 Complex vibration

Control system difficulties may be encountered when exciting the Test item to complex vibration types such as described in par 2.5.6., 2.5.7., 2.5.8. With some control systems ii may be possible to specify incompatible sweep rates and control strategies (statistical degrees of freedom and number of control points). In such cases, the control system may, without warning, perform the test incorrectly, in that sweeps may not be completed or that tolerances may be exceeded. The capability of the control system to conduct the test as specified in the Test Instruction should be verified prior to undertaking the test. Any deviation from the Test Instruction should be noted in the Test Report.

5.2 Installation Conditions of Test item

5.2.1 General

Test items can vary from materiel components to structural assemblies containing several different subassemblies. Consequently, the installation procedures need to take in account the following:

– fixing should simulate actual in service mounting attachments (including vibration isolators, fasteners torques, if appropriate),

– all the connections (cables, pipes, etc.) should be installed in such a way that they impose stresses and strains on the test item similar to those encountered in service.

The following should also be considered:

– the possibility of exciting the test item simultaneously along several axes using more than one vibration generator,

– resonances.

– the direction of gravity or the load factor (mechanisms, vibration isolators, etc.) must be taken into account by compensation or by suitable simulation.

5.2.2 Test set-up

Unless otherwise specified, testing should be accomplished in three mutually perpendicular axes in turn with the test item oriented as during normal operation. The test item should be hard mounted directly to the vibrator, using its normal mounting method and a suitable fixture. The stiffness of the mounting fixture should be such that its induced natural frequencies are as high as possible and do not interfere with test item response.

Alternatively (for example large complicated materiel), the test item may be suspended from a structural frame. In this case, the test set up shall be such that its rigid body modes (translation and rotation) are lower than the lowest test frequencies. Vibration shall be applied by means of a rod or suitable mounting device running from the vibrator to a relatively hard, structurally supported point on the surface of the test item.

Control instrumentation should be mounted as specified in the Test Instruction, or its location and mounting determined according to a procedure included in the Test Instruction.

The fixture should apply the excitation to the test item so as to simulate as accurately as possible the vibration transmitted in service.

5.2.3 Specific platform

The following instructions are also applicable

a. Materiel transported as secured cargo:

Mount the test item securely in its transport configuration on the vibration fixture/table using restraints and tie-downs typical of those to be used during actual transport. Testing should be conducted using representative stacking configurations. The excitation should be applied through all representative axes. Materiel is not normally operated in this mode.

b. Materiel carried externally on aircraft:

Where practicable, testing should be accomplished with the mounting lugs in the normal carriage position. Suspend the store from a structural frame by means of its normal mounting lugs, hooks and sway braces which simulate the operational mounting apparatus.

Alternatively, the store may be hard-mounted directly to the shaker, using its normal mounting lugs and a suitable fixture.

For both methods, where applicable, launcher rails shall be used as part of the test set-up.

Instrumentation to monitor the vibratory response of the store should be mounted on at least two relatively hard points or rings within the store, in the nose section and in the aft section. For stores such as bombs with non-integral tail cones, the aft-section mounting point should be in the aft most section of the main body of the store. At each mounting point or ring, two accelerometers should be mounted one in the vertical and one in the lateral plane. (Longitudinal direction is along the axis of the store, the vertical direction is defined as perpendicular to the longitudinal axis and contained in a plane passing through the mounting lugs).

c. Materiel installed in ships.

Materiel should be mounted in its normal configuration with normal shock/vibration isolation mounts used throughout the test.

5.3 Test Preparation

5.3.1 Pre-conditioning

The test item should be stabilized to its initial climatic and other conditions as stipulated in the

Test Instruction.

5.3.2 Operational Checks

All operational checks including all examinations should be undertaken as stipulated in the Test Instruction.

The final operational checks should be made after the materiel has been returned to rest under pre-conditioning conditions and thermal stability has been obtained.

5.4 Procedures

5.4.1 General

Conduct the relevant following procedure in accordance with the Test Instruction.

5.4.2 Procedure 1 - Swept Frequency Sinusoidal Vibration

Step 1. Pre-condition (par.5.3.1)

Step 2. Implement control strategy, including control and monitoring points (par. 2.6)

Step 3. Undertake initial operational checks (par 5.3.2)

Step 4. Apply sinusoidal vibration, and carry out specified operation and functional checks (par 5.3.2)

Step 5. Undertake the final operational checks (par 5.3.2)

Step 6. Repeat steps 1 to 5 for the other specified axes

Step 7. Record the information required

5.4.3 Procedure 2 Fixed Frequencies Sinusoidal Vibration

Step 1. Precondition (par 5.3.1)

Step 2. Implement control strategy, including control and monitoring point (par 2.6)

Step 3. Undertake initial operational checks (par 5.3.2)

Step 4. Determine the fixed frequencies : these are either specified in the Test Instruction or obtained from the preliminary vibration survey procedure contained in the Test Instruction

Step 5. Apply the sinusoidal vibration to the test item and carry out the specified operational and functional checks (par. 5.3.2.)

Step 6. Undertake the final operational checks

Step 7. Repeat steps 3, 5 and 6 for other specified frequencies.

Step 8. Repeat steps 1 to 6 for other specified axes.

Step 9. Record the information required.

5.4.4 Procedure 3 - Random Vibration or Complex Vibration

Step 1. Pre-condition (par. 5.3.1)

Step 2. Implement control strategy including control and monitoring points (par. 2.6). This step is conducted at low vibration level otherwise with a dynamically representative model of the test item.

Step 3. Undertake the initial checks (par. 5.3.2). The initial checks may include establishing the location of any critical frequencies.

Step 4. Subject the test item to the test severity specified, and conduct operational and functional checks specified (par 5.3.2)

Step 5. Undertake the final checks (par 5.3.2).

Step 6. Repeat Steps 1 to 5 for the other specified test axes.

Step 7. Record the information required.

5.4.5 Procedure 4 - Random Vibration (Stores)

Step 1. Pre-condition (par. 5.3.1)

Step 2. Implement control strategy including control and monitoring points (par 2.6). This step is first conducted at low vibration level, otherwise with a dynamically representative model of the store.

Step 3. Undertake initial checks (par. 5.3.2.) The initial checks may include establishing the location of any critical frequencies.

Step 4. Apply broadband vibration to the store using an input spectrum shape of the forward control accelerometer response spectrum. The input level shall be at least 6dB down from the calculated response level of the forward accelerometer. Identify those frequencies at which the response monitoring acceleration exceed the applied input, in the direction of applied vibration, by 6dB or greater. There may be different frequencies for the forward and aft accelerometers.

Peak or notch the applied input spectrum until both the forward and aft-mounted accelerometers in the direction of applied vibration at their respective frequencies identified above equal or exceed required test levels.

It may be necessary to move the points of attachment between shaker and store until locations are found where both ends of the store are simultaneously excited to their respective test levels.

The off-axis accelerometer response (those accelerometers 90 degrees to the applied vibration) should be examined. For each frequency where the response of an off-axis accelerometer is above in-axis response levels, the following actions are suggested. For each of these frequencies, calculate the ratio of required to observed levels for each accelerometer which was in the direction of vibration (in-axis) and those perpendicular (off-axis) accelerometers which have excessive levels.

Average these ratios for each frequency. The input vibration spectrum may then be adjusted so that, at each of these frequencies, their respective average value is equal to unity.

The method described above provides for single excitation. If the desired vibratory response cannot be achieved, m ultiple excitation may be applied.

Step 5. Undertake the final checks (para 5.3.2).

Step 6. Repeat Steps 1 to 5 for the test axes.

Step 7. Record the information required.

6 FAILURE CRITERIA

The test item performances shall meet all appropriate specification requirements during and following the application of vibration.

ANNEX A

GUIDANCE FOR INITIAL TEST SEVERITIES

This annex is to be used only if measured data will not be available in the early stages of a program and the information is vital to the design of the materiel. If there is a possibility to obtain early measurements on the materiel platform then the severities developed using the information in this appendix should be considered as preliminary.

It should be pointed out that the data utilized in this appendix for developing the prediction of the test levels are based on the enveloping of measured data and may be more or less severe than the environment being simulated. The definition of actual measured environments of specific platforms and operating conditions may be found in AECTP-200. The following initial test severities should be tempered with engineering judgment when utilized :

1 TRANSPORT

All materiel transported as secured cargo by land, sea or air will encounter this environment.

1.1 Ground

The land mobile environment is characterized by broadband vibration resulting from the interaction of vehicle suspension and structures with road and surface discontinuities. These conditions may be divided into two phases, common carrier transportation and mission/field transportation.

Common carrier transportation is movement from the manufacturer's plant to any storage or user installation.

Mission/field transportation is that movement of materiel as cargo where the platform may be two wheeled trailers, 2-1/2 ton to 10-ton trucks, semi-trailers, and/or tracked vehicles. In addition to the paved highway, the vehicles will traverse unimproved roads and unprepared terrain (off-the-road) under combat conditions.

In the development of the vibration test it must be determined if materiel will experience the common carrier, mission/field, or both transportation environments. For materiel that will only be transported via common carrier, test levels and durations are given in figure 1. Materiel that will experience both transportation environments should be tested at the higher levels associated with the mission/field transportation, which are shown in figures 2 to 4. The test must be developed from a typical mission/field transportation scenario to obtain the proper mix and representative combination of platform and mileage requirements.

Figure 1

Depicts the common carrier test severity. These curves are based upon data measured at the cargo floor of seven different configurations of trucks and tractor-trailer combinations. Both conventional suspensions and air-cushioned suspensions are represented. The data was collected from typical highways with rough portions as part of the data base.

Test duration: see fig. 1 (60 min/axis represent 1 600 km.)

Note: The case of heavy and isolated materiel is not taken into account. For this case, the test frequency bandwidth should be extended in low frequency.

Figure 2

Represents the cargo test severity at the floor of a two-wheeled trailer. The data include differing vehicle load conditions traversing over specially design courses ranging from paved highway to off road conditions at various vehicle speeds.

Displacement at low frequency requires the use of high stroke shaker. If an hydraulic shaker which is not capable of generating high frequencies is used, then in this case only, the test may be performed in two steps by using of two shakers with adjacent frequency ranges.

Test duration: see fig. 2 (32 min/axis represent 50 km.)

Figure 3

Represents the cargo test severity at the cargo bed of a composite of tactical wheeled vehicles. The data include differing vehicle loading conditions traversing over specially designed courses ranging from paved highway to off road conditions at various vehicle speeds.

Test duration: see fig. 3 (40 min/axis represent 800 km.)

Figure 4

Represents the test severity of tracked vehicles. The data utilized for establishing these spectra where derived from measurements of vehicles operating at various speeds over specially designed courses ranging from paved highway to off road conditions.

Figure 4 only concerns heavy tracked vehicles. For light vehicles, it is recommended to tailor the severity. This process should be lead to a swept frequency narrow band random vibration on wide band random vibration more representative of the track patter. (see STANAG 4242)

Test duration: see fig. 4 (45 min/axis represent 1600 km.)

1.2 Air

The air transport environment is dependent upon the type of aircraft, (jet, propeller or helicopter).

a) Jet - Figure 5 represents the test severity on the cargo floor and the container of typical jet transports.

   Test duration: see fig. 5 (1h/axis represent 8 hours flight.)
   (2 h/axis is sufficient for most application)

b) Propeller - Figure 6 represents the test severity on the cargo floor of propeller aircraft.

   Test duration: see fig. 6 (60 min/axis represent 6 hours flight.)

c) Helicopter - Figure 7 represents the test severity on the cargo floor of helicopters.

   Test duration: see fig. 7

   It is important to make sure that the frequency bands (10-30 Hz and 20-60 Hz) include the first frequency of the main rotor.

1.3 Shipborne

Table 4 should be used for materials transported by ship.

Test duration: see table 4.

2 MISSION INDUCED VIBRATION

2.1 Propeller aircraft

Service vibration frequency spectra for materiel installed in propeller aircraft consist of a broadband background with superimposed narrowband peaks. The background spectrum results from various random sources including many periodic (not pure sinusoidal) components due to the rotating elements (engines, gearboxes, shafts, etc.) associated with turbo-props. The peaks are produced by passage of pressure fields rotating with the propeller blades. These occur in relatively narrowbands centered on the propeller passage frequency (number of blades multiplied by the propeller rpm) and harmonics.

The primary peak frequencies of engines are many and varied, therefore, the broadband spectrum is recommended as a fall back level.

Most current turbo-prop aircraft have relatively constant-speed engines. This means that rpm is held constant and power changes are made through fuel flow changes and variable-pitch blades, vanes, and propellers. These machines produce the fixed frequency peaks of figure 6. These peaks have an associated bandwidth because there is minor rpm drift and the vibration is not pure sinusoidal.

These vibration environments can be practically approximated in the laboratory by the source fixed frequency test. Many vibration problems in this type of environment are associated with the coincidence of materiel vibration modes and the excitation peaks.

(1) Test levels

The test levels of table 1 can be used with the spectra of figure 8a and b.

(2) Test duration

See table 1 (60 min/axis represent 1 500 flight hours).

2.2 Jet aircraft

The vibration environment for materiel installed in jet aircraft stems from four principal mechanisms. These vibrations are broadband random except where the elastic response of primary aircraft structure is the source. These are as follows:

(1) Engine noise impinging on aircraft structure

(2) Turbulent aerodynamics flow along external aircraft structure

(3) Pressure pulse impingement due to repetitive firing of guns

(4) Airframe structural motions due to maneuvers, aerodynamics buffets, landing, taxi, etc.

The initial test levels provided in this section consider sources (1), (2) and (4). Another method covers source (3).

(1) Test levels

Test levels approximating jet-noise-induced and flow-induced vibration may be derived from table 2 and figures 9 and 10.

(2) Test duration

See fig. 9 (60 min/axis represent 1 500 flight hours).

2.3 Helicopter aircraft

Helicopter vibration is characterized by broadband random with superimposed strong vibration peaks, as depicted in figure 11. These peaks are generated by the rotating components in the helicopter, such as the main and tail rotors, engine and gear meshing. The operating speeds of these components under flight conditions are essentially constant, varying by about five percent.

The relative levels of these peaks differ throughout the helicopter, depending on the proximity of the sources, geometry of the aircraft, and location of the test item. Thus, the need for measured data is especially acute. The major peaks in the helicopter vibration spectrum are usually associated with the main rotor. However, each type of helicopter will have different sources within different areas of each aircraft. Since the vibration environment is dominated by discrete frequency peaks, it is logical to use some of these frequencies for exposure in the laboratory test. Four frequencies are chosen for the tests. For materiel mounted on engines, refer to paragraph a.

(1) Test levels

Three initial test levels have been provided to cover expected vibration levels and ranges, figure 11.

(2) Test duration

See fig 11 (60 min/axis represent 500 flight hours).

2.4 Assembled jet aircraft external stores

Three major sources of store vibration arise from captive flight conditions, i.e. ; store aerodynamic boundary layer turbulence, aircraft induced effects and aircraft buffet maneuvers.

The primary source of store vibration is broadband aerodynamic turbulence, which is a function of dynamic pressure, store shape and other parameters such as density. This vibration is relatively independent of the carrying aircraft and mounting location on the aircraft, and is induced along the entire length of the store. Therefore it is difficult to simulate this vibration by a point input, such as from a vibration shaker. Therefore, the acoustic test (METHOD 402) is recommended for this environment.

The lower frequency portion of the assembled store vibration spectrum comes from aircraft induced vibration, and where appropriate buffet maneuvers.

(1) Test levels and duration (captive flight).

The initial test severities for aircraft induced vibration are presented in figure 12, whilst those for buffet maneuvers are presented in figure 13.

2.5 Assembled helicopters external stores

Assembled external stores carried on helicopters experience a service environment characterized by complex waveforms, much like materiel installed within the helicopter.

1). Test levels and durations :

The test levels and durations shall be as shown in figure 11.

2.6 Materiel installed in externally carried stores

Materiel installed in an externally carried store will experience a broadband vibration spectrum that will depend on the captive carry response of the store. Vibration testing of materiel installed in the externally carried should be input control testing.

(1) Test levels and durations :

The initial test levels are shown in table 3 and figure 14 for jet aircraft. Table 1 and 2 and figures 8a. and b. for propeller aircraft and figure 11 for helicopters. Durations are given in appropriate tables.

2.7 Ground mobile

The ground mobile environment includes conditions experienced by materiel installed in wheeled vehicles, trailers, and tracked vehicles. This vibration environment consists largely of broadband random vibration resulting from the interaction of the vehicle suspension and structure with the various road surfaces. The nature of the terrain, vehicle speed, vehicle dynamic characteristics, and suspension loading affect vibration responses.

The wheeled vehicle and two-wheeled trailer vibrations spectra are predominantly random with peaks and notches at discrete frequencies across the total spectra. The environment can be simulated by a broadband random test.

The tracked vehicle vibration spectra are a complex random vibration environment which is a broadband random background with the strong influence of higher energy bands of random vibration energy created by the interaction of the track with the ground surface and with the vehicle sprockets. This environment can be best simulated by a swept frequency narrow band random on wide band random vibration. However for a fall back level, it may be more desirable to utilize a wide band random vibration spectra as the exact environments are related to specific tracked vehicles.

(1) Test levels and durations :

See fig. 1, 2, 3 and 4 .

2.8 Materiel and stores installed on ships

Materiel and stores carried on ships experience an environment consisting of sinusoidal excitation from the propeller shaft(s) and random excitation from water flow around the hull. The mounting method and location within the ship must be considered when establishing (allocating) vibration levels.

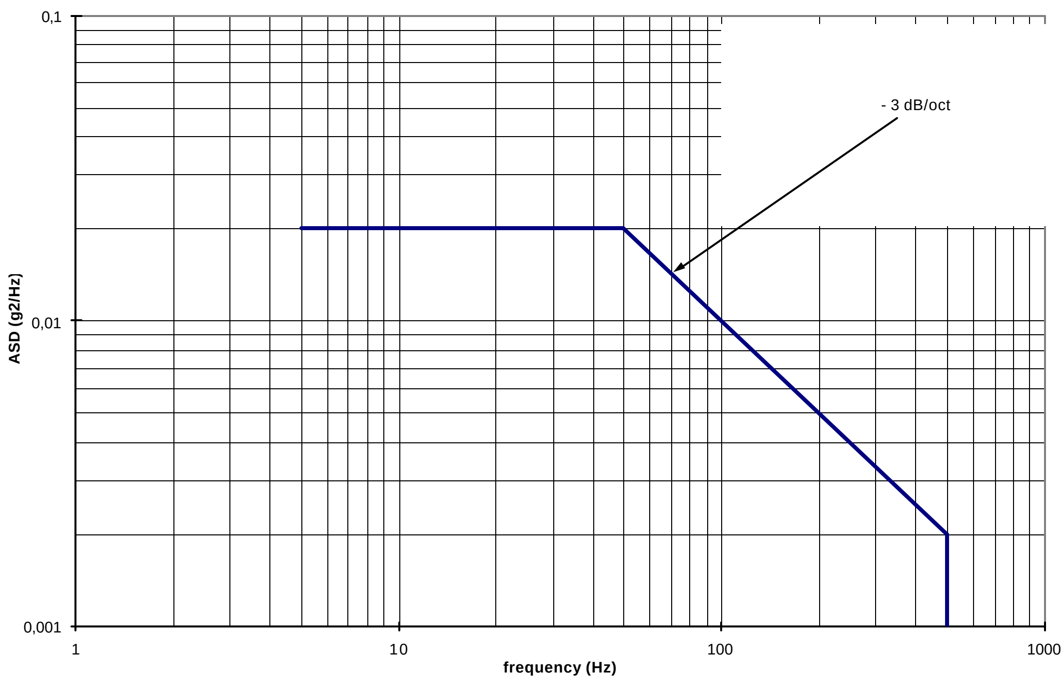
(1) Test levels and durations :

The test levels and durations shall be as shown in table 4.

FIGURE 1
GROUND WHEELED COMMON CARRIER

Duration : 60 min/axis

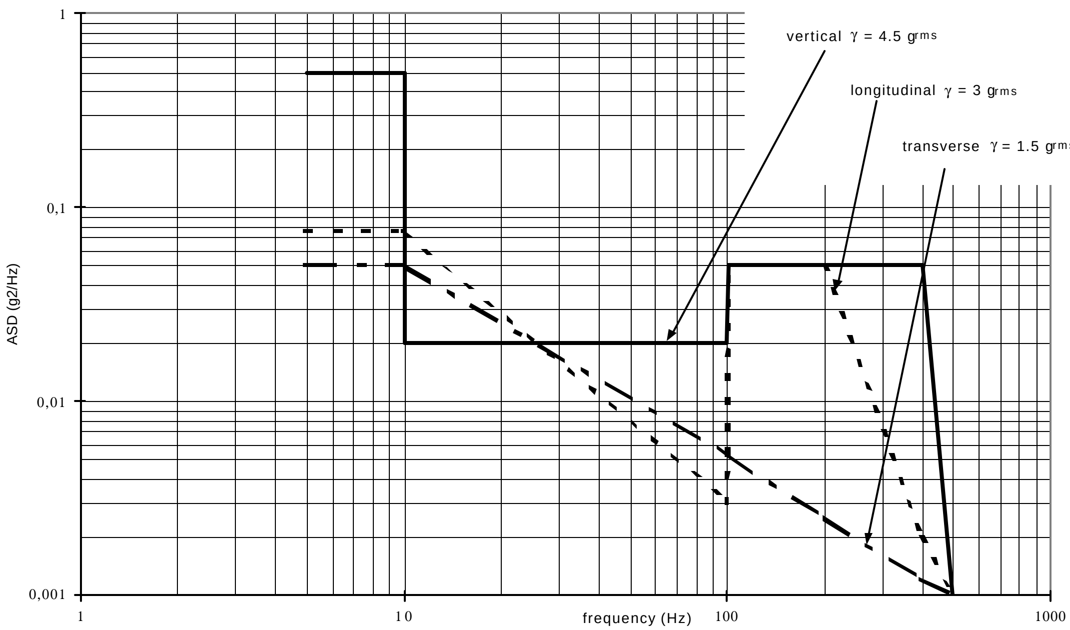
All axes : ϒ = 1.8 g_{rms}



Ref : developed from DEF STAN 0035

FIGURE 2
TWO WHEEL TRAILER

Duration : 32 min/axis



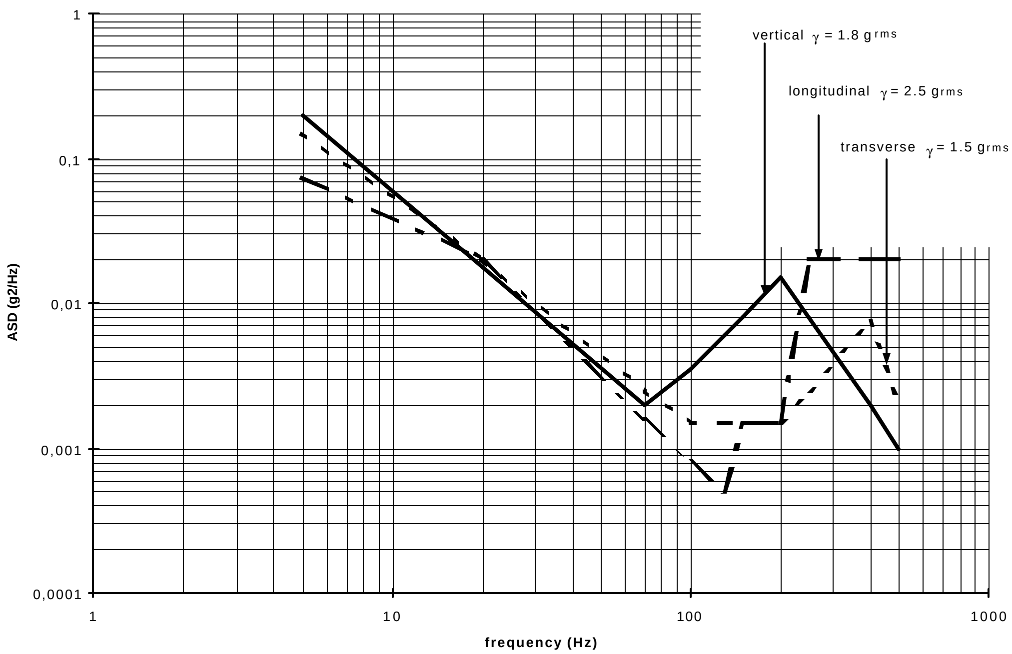
F	Vert.	Trans.	Long.
5	.5	.05	.075
10	.5	.05	.075
10	.02		
100	.02		.003
100	.05		.05
200			.05
400	.05		
500	.001	.001	.001

Ref : developed from ITOP 1.2.601

FIGURE 3

TACTICAL VEHICLES - ALL TERRAIN

Duration : 40 min/axis

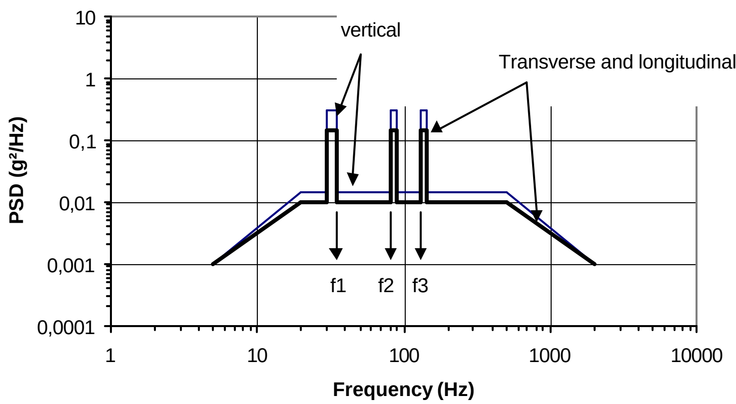


F	Vert.	Trans.	Long.
5	.2	.15	.075
20			.02
70	.002		
100		.0015	
130			.0005
150			.0015
200	.015	.0015	.0015
250			.02
400		.0075	
500	.001	.002	.02

Ref : developed from ITOP 1.2.601

FIGURE 4

TRACKED VEHICLES



Bandwidth of the harmonically related narrow bands : 5 Hz, 10 Hz and 15 Hz respectively.

Swept frequency ranges of the narrow bands : $20 \text{ Hz} < f_1 < 170 \text{ Hz}$

$40 \text{ Hz} < f_2 < 340 \text{ Hz}$

$60 \text{ Hz} < f_3 < 510 \text{ Hz}$

Wideband random spectrum amplitudes (g²/Hz)					Swept narrow band random amplitudes (g²/Hz)		
Axis	Spectrum breakpoints - frequency (Hz)				Harmonically related swept freq. (Hz)		
	5	20	510	2000	f_1 *	f_2	f_3
Vertical	0.001	0.015	0.015	0.001	0.300	0.300	0.300
Transverse	0.001	0.010	0.010	0.001	0.150	0.150	0.150
Longitudinal	0.001	0.010	0.010	0.001	0.150	0.150	0.150

*When sweeping up the frequency range, the value of f_1 may be ramped up from 0.08 g²/Hz at 20 Hz to the specified value at 40 Hz, and vice-versa when sweeping down the frequency range.

The sweep rate should be within the range one half to one octave per minute. Minimum number of sweeps = 2, i.e. : one sweep up the frequency range followed by one sweep down the frequency range. When the centre frequency of the first harmonically related sweeping band (f_1) is at its lowest frequency, the lower frequency band edge of this sweeping band and the lower band edge of the 0.015 g²/Hz level wideband (for the vertical axis) coincide at 20 Hz. When the centre frequency of the third harmonically related sweeping band (f_3) is at the highest frequency, the upper band edge of this sweeping band and the upper band edge of the 0.015 g²/Hz level wideband (for the vertical axis) coincide at 510 Hz.

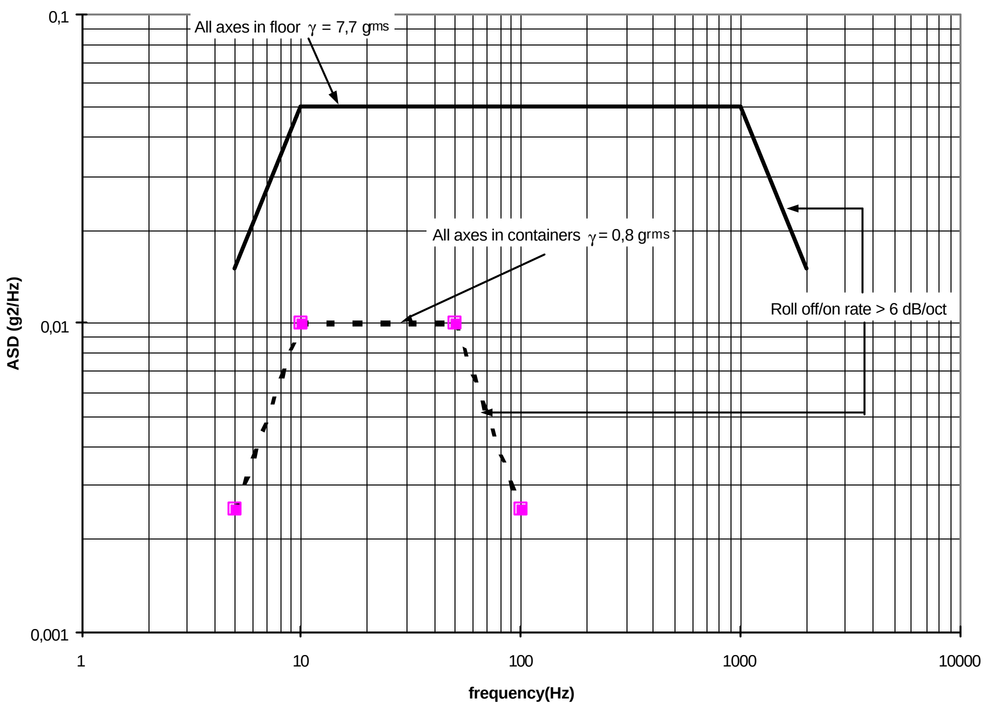
Duration : 4 hours per axis

Ref : developed from STANAG 4242

FIGURE 5

JET AIRCRAFT TRANSPORT

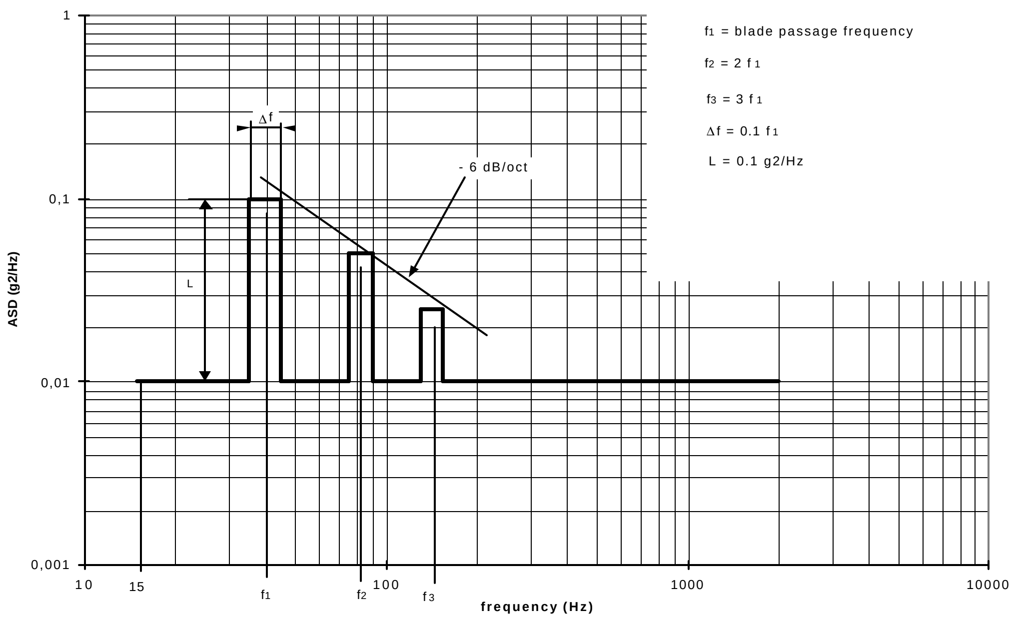
Duration : 1h/axis



Ref : developed from MIL STD 810

FIGURE 6
PROPELLER AIRCRAFT TRANSPORT

Duration : 2h/axis



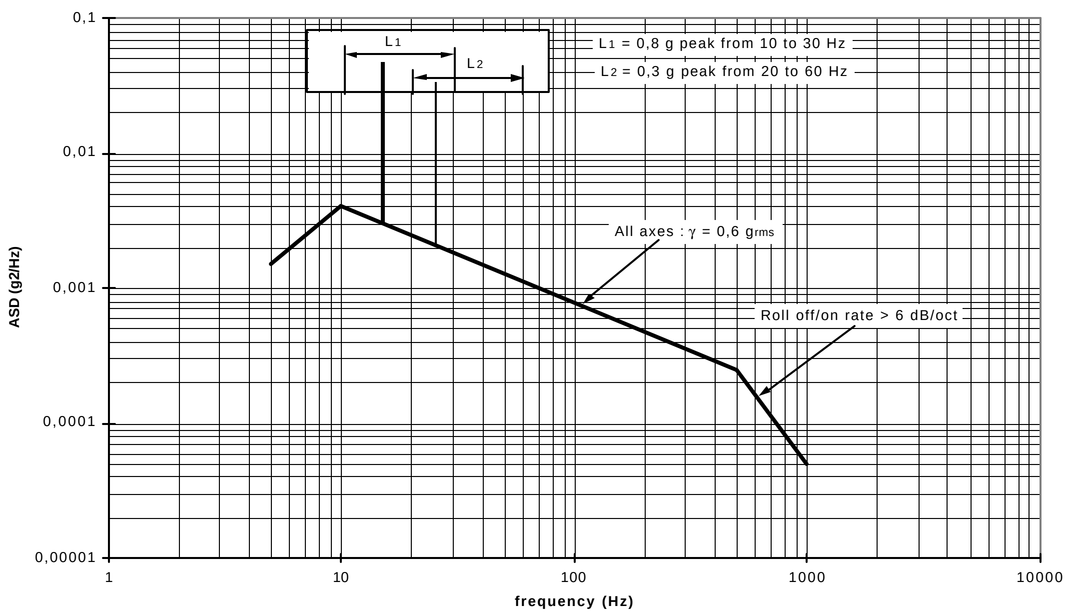
Ref : developed from MIL STD 810

FIGURE 7

HELICOPTER TRANSPORT

Duration : 2 hours per axis for one cycle of L1 and L2 with both cycles being run simultaneously

Note : The sweep rate should be adjusted to provide one cycle



10 Hz :	4.0 10^{-3} g²/hz
500 Hz :	2.5 10^{-4} g²/Hz

Ref : developed from DEF STAN 0035

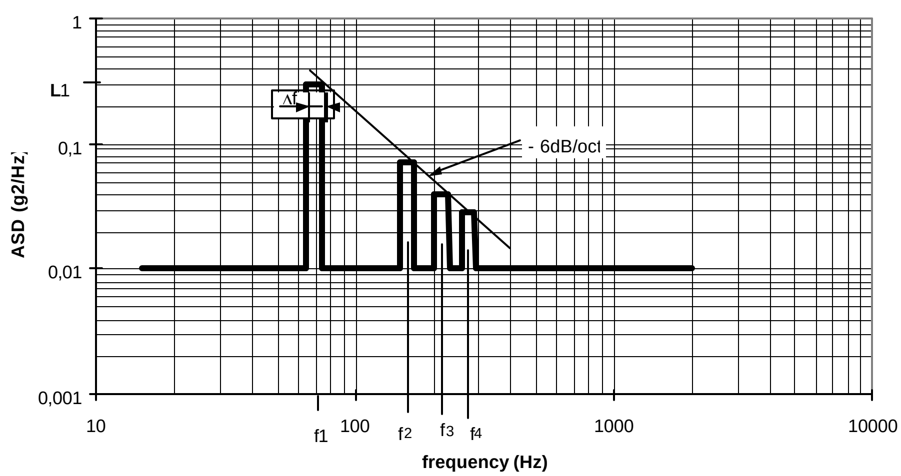
FIGURE 8

PROPELLER AIRCRAFT

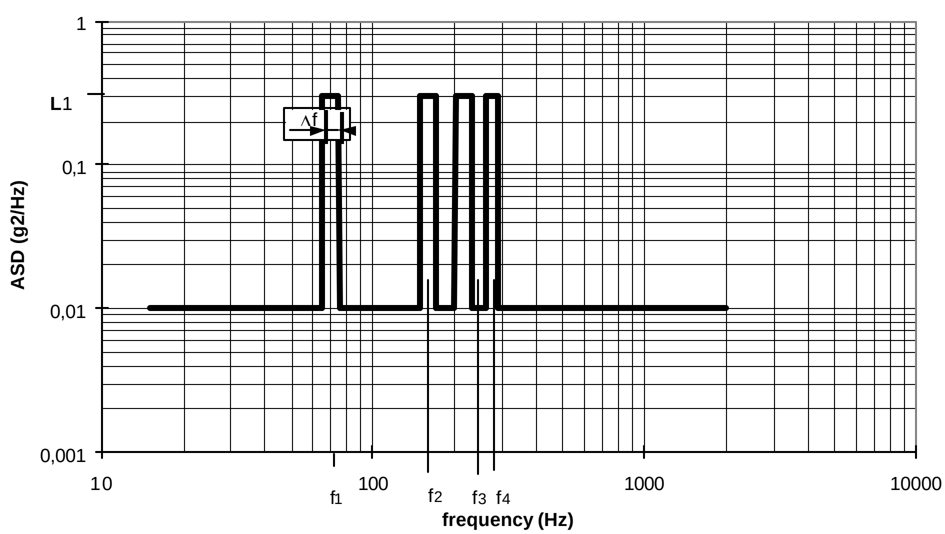
MATERIEL AND ENGINE AREA

Duration : 1h/axis

Aircraft spectrum



Engine spectrum



Ref : developed from MIL STD 810

TABLE 1

SUGGESTED FUNCTIONAL TEST CONDITIONS FOR PROPELLER AIRCRAFT MATERIEL (SEE FIGURE 6, 8a and 8b)

Materiel location (2)	Vibration level of L1 at f_1 (g^2/Hz) (3)
In fuselage or wing forward of propeller	0.10
In fuselage or wing aft of the propeller	0.20
In engine compartment, empennage, or pylons	0.30
Materiel mounted directly on aircraft engines	0.50

(1) f_1 = fundamental excitation frequency, (blade passage frequency)

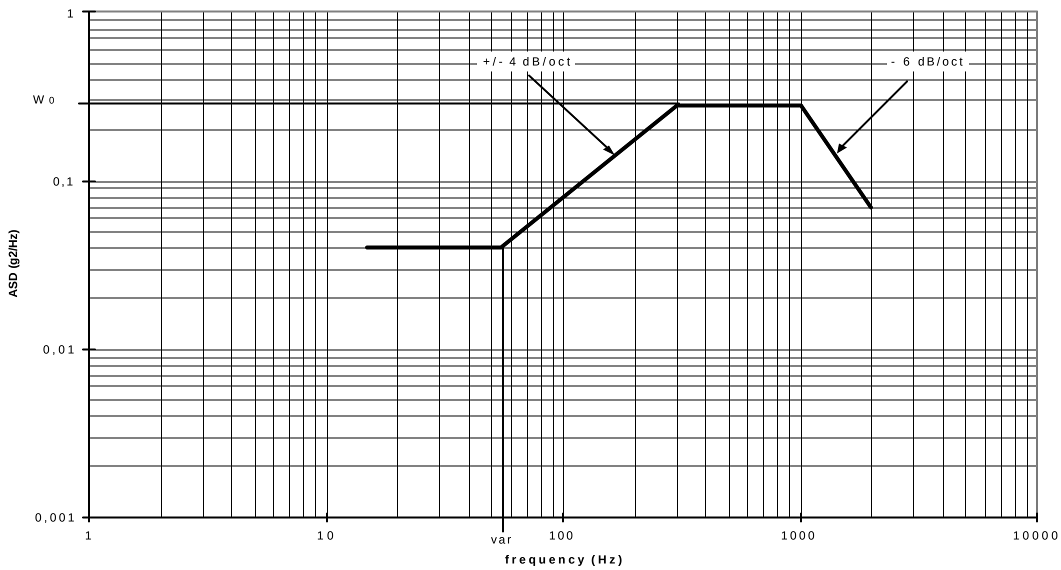
$f_2 = 2f_1$, $f_3 = 3f_1$, $f_4 = 4f_1$.

(2) Increase test levels by 6dB for materiel mounted on fuselage or wing skin within one propeller blade radius of the plane of the propeller disk. For all other skin mounted materiel, increase levels by 3dB.

(3) Bandwidth is 10% of Fi for constant speed excitation. When excitation is not constant-speed, bandwidth will encompass operating speeds for cruise and high power operation.

FIGURE 9
SUGGESTED VIBRATION SPECTRUM FOR A JET AIRCRAFT MATERIEL

Duration 1 hour/axis



For W_0 see table 2

Ref : developed from MIL STD 810

FIGURE 10

REDUCTION FACTOR FOR MASS LOADING FOR ASD LEVELS FOR JET AIRCRAFT MATERIEL

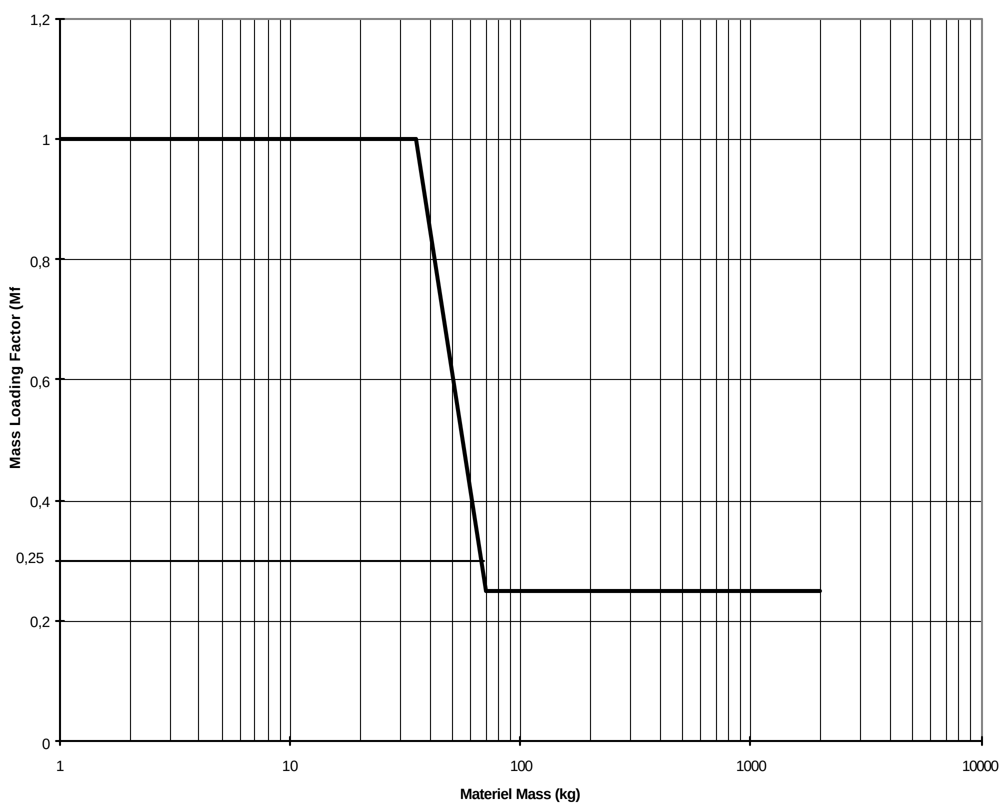


TABLE 2
BROADBAND VIBRATION TEST VALUES FOR JET AIRCRAFT MATERIEL

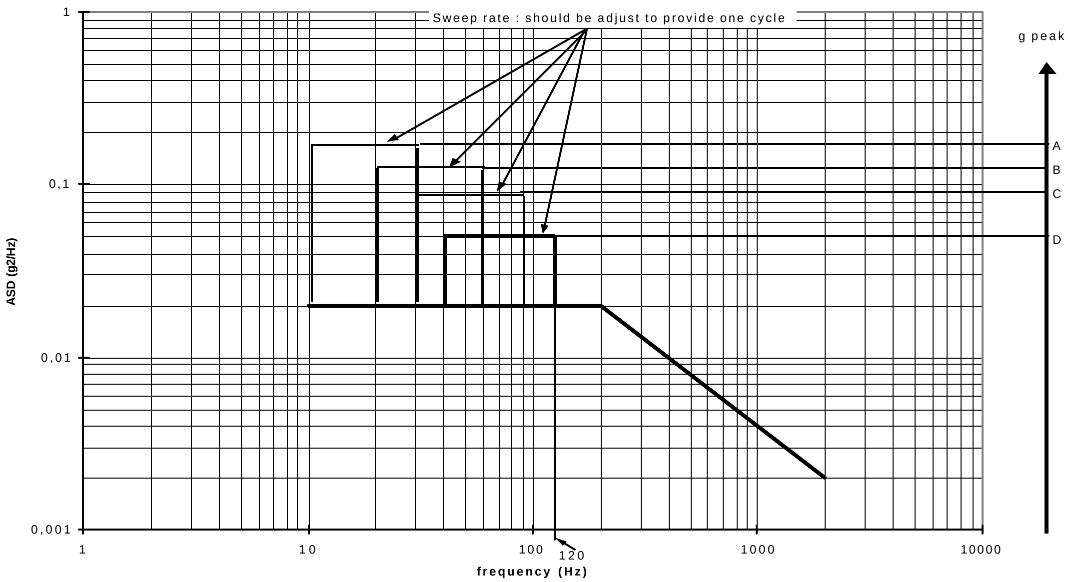
CRITERIA
Aerodynamically induced vibration (figure 9) $W_o = K(q)^2 \times M_f$ Notes 1 and 3 Jet engine noise induced vibration (figure 9) Materiel aft of exhaust plane $W_o = .05\ g^2/Hz$ Notes 2 and 4
DEFINITION
K = 1.17 10-11 for cockpit panel equipment and materiel attached to structure in compartments adjacent to external surfaces that are smooth, free from discontinuities K = 6.09 10-11 for materiel attached to structure in compartments adjacent to or immediately aft of external surfaces having discontinuities (cavities, chins, blade antennas, speed brakes, etc) and materiel in wings, pylons, stabilizers and fuselage aft to trailing-edge wing root. Q = 57 500 N/m² or maximum aircraft q, whichever is less. Mf = mass loading factor (see figure 10)

Notes

1. Envelop aerodynamically induced and jet engine induced and use the worst-case composite.
2. If aircraft has more than one engine, Wo, add +3 dB
3. For materiel weighing more than 36.6 kg the vibration test level may be reduced according to figure 10 (Mf).
4. For engines with after-burner, Wo, add +6 dB.
5. For instrument panel equipment, reduce the 0.04 g²/Hz value of figure 9 by 3 dB, Wo by 6dB.

FIGURE 11
HELICOPTER - INSTALLED MATERIEL AND STORES

Duration 1h/axis



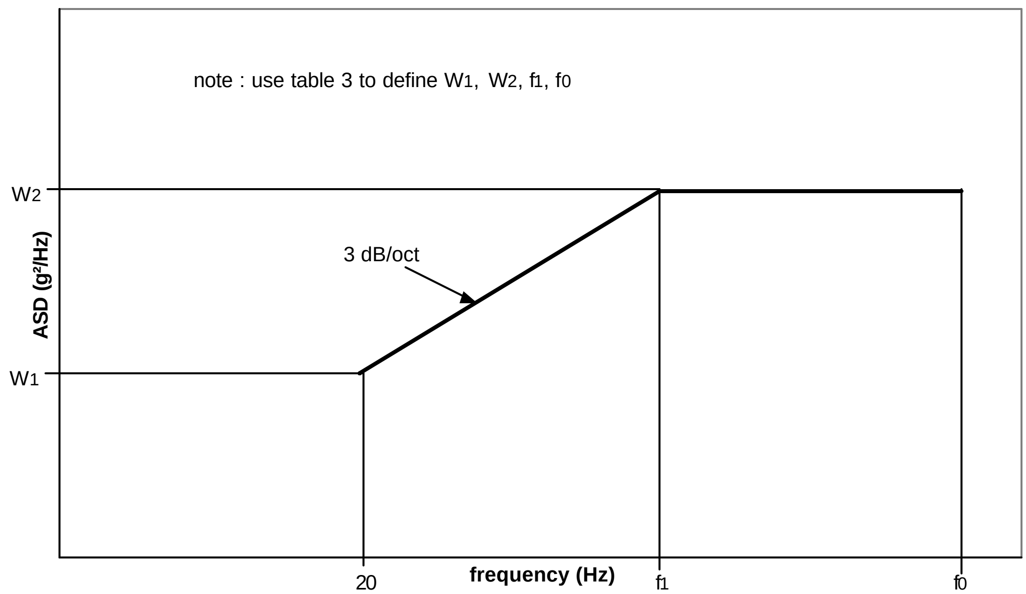
Sweepings :

10 to 30 Hz
20 to 60 Hz
30 to 90 Hz
40 to 120 Hz

	General	Instrument panel	Engine	Stores
A	2.5 g	1.7 g	5 g	3.75 g
B	2.0 g	1.4 g	5 g	3.00 g
C	1.5 g	1.0 g	5 g	2.25 g
D	1.0 g	0.7 g	5 g	1.50 g

Ref : developed from GAM EG 13

FIGURE 12
RESPONSE THRESHOLD SPECTRUM FOR ASSEMBLE EXTERNAL STORE CARRIED ON JET AIRCRAFT



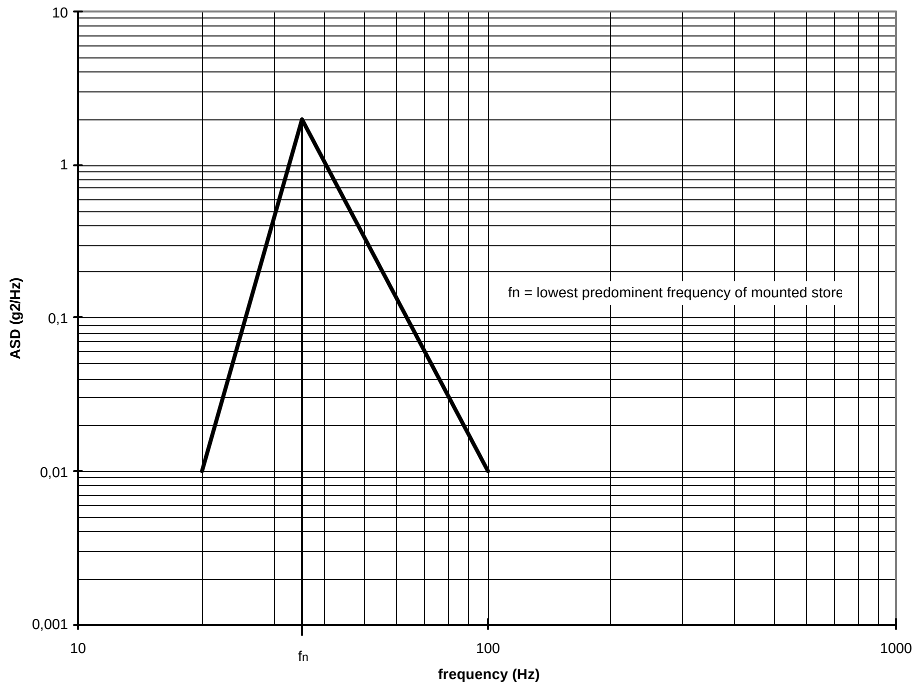
Ref : developed from MIL STD 810

FIGURE 13

BUFFET MANOEUVRE VIBRATION RESPONSE SPECTRUM

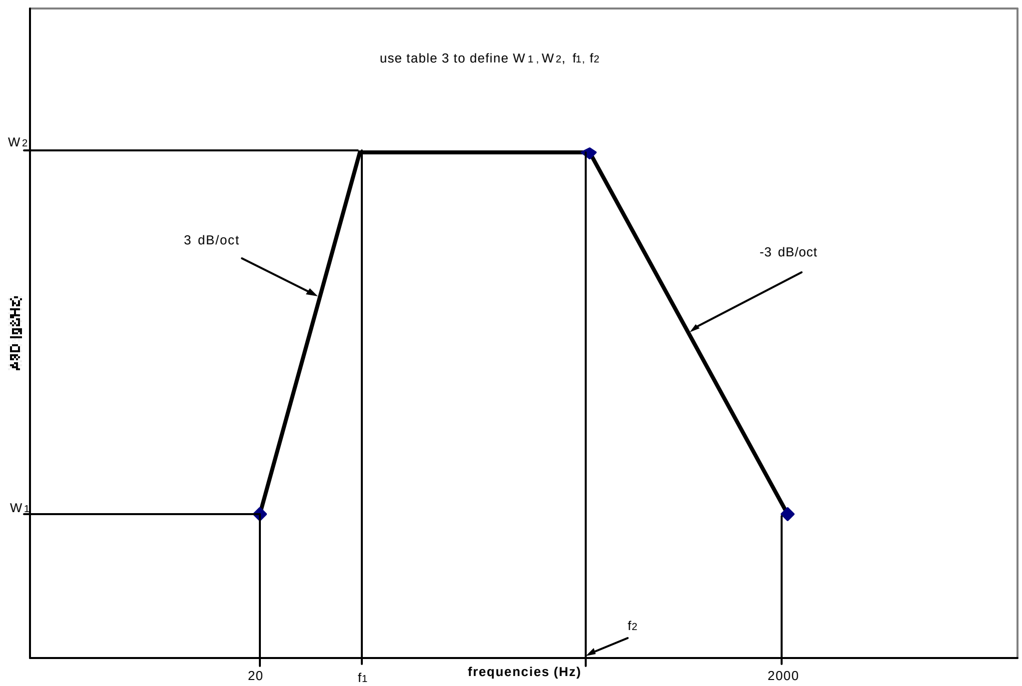
Duration : 10 minutes based upon following assumptions :

- average manoeuver : 6 seconds
- total captive flight of 150 hours with a total of 100 buffet manoeuvers in the lifetime



Ref : developed from MIL STD 810

FIGURE 14
MATERIEL IN ASSEMBLED EXTERNAL STORES



Ref : developed from MIL STD 810

TABLE 3 - VIBRATION CRITERIA FOR EXTERNAL STORES CARRIED ON AIRPLANES

$$\mathbf{W_1} = 5\text{x}10^{-3} \text{ x } K \text{ x } A_1 \text{ x } B_1 \text{ x } C_1 \text{ x } D_1 \text{ x } E_1 \quad (g^2/Hz) \quad (1)$$

$$\mathbf{W_2} = (H)\ (q/\rho)^2 \text{ x } K \text{ x } A_2 \text{ x } B_2 \text{ x } C_2 \text{ x } D_2 \text{ x } E_2 \quad (g^2/Hz) \quad (1)$$

for $M \leq 0.90$, $K = 1.0$ for $0.90 \leq M \leq 1.0$, $K = -4.8 \text{ x } M + 5.32$ for $M \geq 1.0$, $K = 0.52$ *(2)*

$f_1 = C\text{x}10^5 \text{ x } (t / R^2)$, (Hz) *(3), (4), (5)* $f_2 = f_1 + 1000$, (Hz) *(3)* $f_o = f_1 + 100$, (Hz) *(6),(7)*

Configuration	Factors		Configuration	Factors	
Aerodynamically clean	A_1	A_2		B_1	B_2
▪ Single store	1	1	▪ Powered missile, aft half	1	4
▪ Side by side stores	1	2	▪ Other stores, aft half	1	2
▪ Behind other store(s)	2	4	▪ All stores, forward half	1	1
Aerodynamically dirty (8)	C_1	C_2		D_1	D_2
▪ Single and side by side	2	4	Field assembled sheet metal		
▪ Behind other store(s)	1	2	▪ Fin / tailcone unit	8	16
▪ Other stores	1	1	▪ Powered missile	1	1
			Other stores	4	4
	E_1	E_2			
▪ Jelly filled firebombs	½	¼			
▪ Other stores	1	1			

M - Mach number
H - Constant = 5.59 (metric unit) (= 5 x 10^{-5} English units)
C - Constant = 2.54 x 10^{-2} (metric units, t and R in meters), or C=1.0 (English units, t and R in inches)
q - Flight dynamic pressure kN/m² (lb/ft²). Define q from Mach number and altitude.
ρ - Store weight density (weight/volume) kg/m^3 (lb/ft^3)
Limit values of ρ to $641 \leq \rho \leq 2403$ kg/m^3 ($40 \leq \rho \leq 150$ lb/ft^3)
t - Average thickness of structural (load carrying) skin – m (in)
R - Store characteristic (structural) radius m (in) (Average over store length)
= Store radius for circular cross section
= Half of major and minor diameters for elliptical cross section
= Half or longest inscribed chord for irregular cross sections

(1) - When store parameters fall outside limits given, consult references
(2) - Mach number correction
(3) - Limit f_1 to 100 £ f_1 £ 2000 Hz
(4) - Free fall stores with tail fins, f_1 = 125 Hz
(5) - Limit C(t/R^2) to : 0.0010 £ (t/R^2) £ 0.020
(6) - f_0 = 500 Hz for cross sections not circular or elliptical
(7) - If f_0 > 1200 Hz, then use f_0 = 2000 Hz
(8) - Configurations with separated aerodynamic flow within the first ¼ of the store length.
Blunt noses, optical flats, sharp corners, and open cavities are some potential sources of separation. Any nose other than smooth, rounded, and gently tapered is suspect.
Aerodynamics engineers should make this judgment.

Store type	Representative parameter values					
	Max q		r		f_1	f_2
	kN / m²	(lb / ft²)	kg / m^3	(lb / ft^3)	Hz	Hz
Missile, air to ground	76.61	(1600)	1602	(100)	500	1500
Missile, air to air	76.61	(1600)	1602	(100)	500	1500
Instrument pod	86.19	(1800)	801	(50)	500	1500
Dispenser (reusable)	57.46	(1200)	801	(50)	200	1200
Demolition bomb	57.46	(1200)	1922	(120)	125	1100
Fire bomb	57.46	(1200)	641	(40)	100	1100

TABLE 4 - SHIPBORNE – VIBRATION

Type of ship	Region	Standard test level peak values and frequency range	Duration of test
Surface ship minesweepers size and above	Mast heads	1 mm from 2 to 14 Hz 0.,8 g from 14 to 100 Hz	1 hr/axis sufficient for most application
	Upper deck, Protected compartments, Hull	0.25 mm from 2 to 14 Hz 0.2 g from 14 to 100 Hz	
Surface ships smaller than minesweepers	Mast heads, Upper decks, Protected compartments, Hull, General test	0.5 mm from 2 to 14 Hz 0.4 g from 14 to 100 Hz	
	Aft (see note 1)	0.5 mm from 2 to 14 Hz 0.4 g from 14 To 100 Hz	
Nuclear and conventional submarines	All	0.125 mm from 2 to 20 Hz 0.2 g from 20 to 200 Hz	

Notes

1. The Aft region is 1/8 of the ship's overall length.
2. Sweep rate : 1 oct/min

METHOD 402

ACOUSTIC NOISE

TABLE OF CONTENTS

ANNEX A

GUIDANCE FOR INITIAL TEST SEVERITY

ANNEX B :

ADDITIONAL TECHNICAL GUIDANCE

METHOD 402

ACOUSTIC NOISE

1 SCOPE

1.1 Purpose

The purpose of this test method is to replicate the acoustic environment incurred by systems, subsystems and units, (hereafter called materiel) during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified acoustic environment without unacceptable degradation of its functional and/or structural performance. It is also applicable for materiel where acoustic noise exci tation is used in preference to mechanical vibrator excitation for the simulation of aerodynamic turbulence.

AECTPs 100 and 200 provide additional guidance on the selection of a test procedure for a specific acoustic environment.

1.3 Limitations

Where a diffuse field acoustic noise test is used for the simulation of aerodynamic turbulence, it is not necessarily suitable for proving thin shell structures interfacing directly with the acoustic noise.

2 GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to an acoustic environment.

(l) Wire chafing

(2) Component fatigue

(3) Component connecting wire fracture

(4) Cracking of printed circuit boards

(5) Failure of waveguide components

(6) Intermittent operation of electrical contacts

(7) Cracking of small panel areas and structural elements

(8) Optical misalignment

(9) Loosening of small particles that may become lodged in circuits and mechanisms

(10) Excessive electrical noise

2.2 Use of Measured Data

Where practicable, field data should be used to develop test levels. It is particulary important to use field data where a precise simulation is the goal. Sufficient field data should be obtained to describe adequately the conditions being evaluated and experienced by the materiel.

2.3 Sequence

Like vibration, the effects of acoustically induced stresses may affect material performance under other environmental conditions, such as temperature, humidity, pressure, electromagnetic, etc. When it is required to evaluate the effects of acoustic noise together with other environments, and when a combined test is impractical, a single test item should be exposed to all relevant environmental conditions in turn. The order of application of the tests should be considered and should be compatible with Life Cycle Environmental Profile.

2.4 Choice of test procedures

The choice of test procedure is governed by the in-service acoustic environments and test purpose. These environments should be identified from consideration of the Life Cycle Environmental Profile as described in AECTP 100.

Three procedures are presented as follows:

Procedure 1: Diffuse field acoustic noise

Procedure 2: Grazing incidence acoustic noise

Procedure 3: Cavity resonance acoustic noise

2.5 Types of Acoustic Excitation

2.5.1 Diffuse Field Acoustic Noise

A diffuse field is generated in a reverberation chamber. Normally wide band random excitation is provided and the spectrum is shaped. This test is applicable to material or structures which have to function or survive in an acoustic noise field such as that produced by aerospace vehicles, power plants and other sources of high intensity acoustic noise. As this test provides an efficient means of inducing vibration above 100 Hz the test may also be used to complement a mechanical vibration test, using acoustic energy to induce mechanical responses in internally mounted material. In this role the test is applicable to items such as installed material in airborne stores carried externally on high performance aircraft. However, as the excitation mechanism induced by a diffuse field is different from that induced by aerodynamic turbulence, when used in this role this test is not necessarily suitable for proving thin shell structures interfacing directly with the acoustic noise.

A practical guideline is that acoustic tests are not required if material is exposed to broadband random noise at a sound pressure level less than 130 dB (ref 20 microPascal) overall, and if its exposure in every one-Hertz band is less than 100 dB (ref 20 microPascal). A diffuse field acoustic test is usually defined by the following parameters.

- The spectrum levels.
- The frequency range.
- The overall sound pressure level.
- The duration of the test.

2.5.2 Grazing Incidence Acoustic Noise

Grazing incidence acoustic noise is generated in a duct, popularly known as a progressive wave tube. Normally, wide band random noise with a shaped spectrum is directed along the duct.

This test is applicable to assembled systems which have to operate or survive in a service environment of convected pressure fluctuations over the surface, such as exist in aerodynamic turbulence. These conditions are particularly relevant to aircraft panels, where aerodynamic turbulence will exist on one side only, and to externally carried stores subjected to aerodynamic turbulence excitation over their total external exposed surface.

In the case of a panel the test item will be mounted in the wall of the duct so that grazing incidence excitation is applied to one side only. An aircraft carried store such as a missile will be mounted co-axially within the duct such that the excitation is applied over the whole of the external surface.

A grazing incidence acoustic noise test is usually defined by the following parameters :

- The spectrum levels.
- The frequency range.
- The overall sound pressure level.
- The duration of the test.

2.5.3 Cavity Resonance

A resonance condition is generated when a cavity, such as that presented by an open bomb bay on an aircraft, is excited by the airflow over it. This causes oscillation of the air within the cavity at a frequency dependant upon the cavity dimensions. In turn this can induce vibration into the structure and components within the cavity. The resonance condition can be induced by the application of a sinusoidal acoustic source, tuned to the correct frequency, to the open cavity. The resonance condition will occur when the control microphone response reaches a maximum in a sound field held at a constant sound pressure level over the frequency range. A cavity resonance test is defined by the following parameters:

- The noise frequency.
- The overall sound pressure level within the cavity.
- The duration of the test.

2.5.4 Additional Technical Guidance

Additional guidance is given in Annex B.

2.6 Material operation

Where relevant, the test item should be functioned and the performance measured and noted during each test phase and/or each acoustic level applied.

3 SEVERITIES

Test levels and durations should be established using projected Life Cycle Environmental Profiles, available data or data acquired directly from an environmental data gathering programme.

When these data are not available, guidance on developing initial test severities are to be found in Annex A. These overall sound pressure levels (OASPL) should be considered as initial values until measured data are obtained.

It should be noted that the test selected may not necessarily be an adequate simulation of the complete environment and consequently a supporting assessment may be necessary to complement the test results.

4 INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- the identification of the test item.
- the definition of the test item.
- the type of test: development, worthiness, qualification.
- whether the test item is required to operate or not during the test.
- the operating checks required: initial, during the test, final.
- for the initial and final checks, specify whether they are performed with the test item installed in the test facility.
- the details required to perform the test, including method of attachment or suspension of the test item.
- the control and monitor points or a procedure to select these points.
- the preconditioning time.
- the definition of the test severity.
- the control strategy.
- the indication of the failure criteria.
- the way of taking into account tolerance excesses in the case of large material.
- any other environmental conditions at which testing is to be carried out, if other than standard laboratory conditions.

4.2 If required

- the effect of gravity and the consequent precautions
- the number of simultaneous test items in the case of Procedure 1.
- tolerances, if different from paragraph 5.1.

5 TEST CONDITIONS

5.1 Tolerances

The test tolerances are given below in table 1

5.2 Control

The control strategy depends upon the type of test and the size of the material.

5.2.1 Control Options

5.2.1.1 Single Point Noise Control

The single point should be defined to provide an optimum control position in the chamber or progressive wave tube.

5.2.1.2 Multiple Point Noise Control

The control points should be selected to define a controlled volume within the reverberation chamber. Control should be based upon the average of the sound pressure levels at each microphone. Where the range of measurements at the monitoring positions does not exceed 5 dB (OASPL) a simple arithmetic average of the sound pressure levels may be used. For a range of 5 dB or greater a logarithmic average of the sound pressure levels should be used.

TABLE 1

(Test tolerances)

PARAMETER	TOLERANCE
Overall sound pressure level averaged over all control microphones,ref specified overall sound pressure level	+ 3dB - 1dB
Overall sound pressure level at each control microphone,ref specified overall sound pressure level	+ 4dB - 2dB
Averaged test spectrum from all control microphones at levels above -15dB[(1)] in 1/3 octave bands,ref specified 1/3 octave band sound pressure levels.	+ 4dB - 4dB
Averaged test spectrum from all control microphones at levels below -15dB[(1)] and above -25dB[(1)] in 1/3 octave bands,ref specified 1/3 octave band sound pressure levels.	+ 6dB - 6dB
Averaged test spectrum from all control microphones at levels -25dB[(1)] and below in 1/3 octave bands,ref specified 1/3 octave band sound pressure levels.	+ 10dB - 10dB
Duration	+/- 5% or +/- 1min whichever is lesser

(1) In octave band, level -15dB becomes -10dB and level -25dB becomes -20dB

5.2.1.3 Vibration Response Control

Where it is necessary to achieve a given vibration acceleration response on the test item, the test spectrum should be adjusted to achieve the required response which may be monitored at either a single point or as the average from multiple monitoring points.

5.2.2 Control Methods

Control can be by either open or closed loop. Open loop control is adequate for progressive wave tubes and for small chambers having a single noise source. Closed loop control is more effective for large chambers having multiple noise sources that cover different bands in the test frequency range.

5.2.3 Overall Accuracy of Control

The uncertainty of measurement of the total measurement system, including statistical errors, should not exceed one third of the specified tolerance for the overall sound pressure level.

5.3 Installation Conditions of Test Item

5.3.1 Diffuse Field Acoustic Noise

The test item should be suspended or otherwise mounted in a reverberation chamber on an elastic system in such a manner that all appropriate external surfaces are exposed to the acoustic field and no surface is parallel to a chamber surface. The resonance frequency of the mounting system with the specimen should be less than 25 Hertz or 1/4 of the minimum test frequency, whichever is the lesser. If cables, pipes etc., are required to be connected to the test item during the test, these should be arranged so as to add similar restraint and mass as in service.

A microphone should be located in proximity to each major different face of the test item at a distance of 0.5 metre from the face or midway between the centre of the face and the chamber wall, whichever is the lesser. The outputs from these microphones should be averaged to provide a single control signal. Where the chamber is provided with a single noise injection point one microphone should be placed between the test item and the chamber wall furthest from the noise source. The orientation of the microphones in such a facility is not critical although the microphone axes should not be set normal to any flat surface.

The microphones should be calibrated for random incidence.

5.3.2 Grazing Incidence Acoustic Noise

System test items such as panels should be mounted in the wall of the duct such that the required test surface is exposed to the acoustic excitation. This surface shall be flush with the inner surface of the duct so as to prevent the introduction of cavity resonance or local turbulence effects. System test items such as stores should be suspended or otherwise mounted centrally within the duct on an elastic support such that all external surfaces are subjected to the progressive wave. The rigid body modes of the system should be lower than 25 Hertz or 1/4 of the lowest test frequency, whichever is the lesser. Care must be exercised to ensure that no spurious acoustic or vibratory inputs are introduced by the test support system or any ancillary structure.

The microphone(s) for control and monitoring of test conditions should preferably be mounted in the duct wall opposite to the test panel. Other positions within the duct may be selected provided that the microphone is positioned so that it responds to only grazing incidence waves and that the necessary corrections are applied to the measured level.

The microphones should be calibrated for grazing incidence.

5.3.3 Cavity Resonance Acoustic Noise

The test item should be suspended or otherwise mounted in a reverberation chamber such that only that part of the specimen to be tested is exposed to the direct application of acoustic energy. All other surfaces should be protected so that their level of acoustic excitation is reduced by 20 dB. Protective coverings should not provide any additional vibration damping to the structure. The microphone for control of the test should be located within the cavity to be tested.

5.3.4 Effects of Gravity

Tests will normally be carried out with the material mounted in the correct attitude, unless it is shown that the performance of the material is not affected by gravity.

5.4 Preparation for Test

5.4.1 Preconditioning

Unless otherwise specified in the Test Instruction the test item should be allowed to stabilise at laboratory ambient conditions.

5.4.2 Inspection and Performance Checks

Inspection and performance checks may be carried out before and after testing. The requirements for these checks should be defined in the Test Instruction. If these checks are required during the test sequence then the time intervals at which they are required should also be specified.

5.5 Procedures

The Test Instruction should stipulate whether the test item is or is not to be operating during the test.

5.5.1 Procedure 1 - Diffuse Field Acoustic Noise Testing

Step 1. Install the test item into the reverberation chamber in accordance with para. 5.3.1.

Step 2. Select microphone positions for control, monitoring and control strategy in accordance with para. 5.2.

Step 3. When using open loop control, remove the test item and confirm the specified overall sound pressure level and spectrum can be achieved in an empty chamber then replace the test item in the chamber.

Step 4. Precondition in accordance with para. 5.5.1.

Step 5. Conduct initial checks in accordance with para. 5.5.2

Step 6. Apply the test spectrum for the specified time. If required, carry out inspections and performance checks in accordance with para. 5.5.2.

Step 7. Carry out the final inspection.

Step 8. Remove the test item from the chamber.

Step 9. In all cases record the information required.

5.5.2 Procedure 2 - Grazing Incidence Acoustic Noise Testing

Step 1. Install the test item in accordance with para. 5.3.2.

Step 2. Select microphone positions for control, monitoring and control strategy in accordance with para. 5.2

Step 3. Precondition in accordance with para. 5.5.1.

Step 4. Conduct initial checks in accordance with para. 5.5.2.

Step 5. Apply the test spectrum for the specified time. If required, carry out inspections and performance checks in accordance with para. 5.5.2.

Step 6. Carry out the final inspection.

Step 7. Remove the test item from the duct.

Step 8. In all cases record the information required.

5.5.3 Procedure 3 - Cavity Resonance Acoustic Noise Testing

Step 1. Install the test item into the chamber in accordance with para. 5.3.3.

Step 2. Locate the control microphone in accordance with para. 5.3.3.

Step 3. Precondition in accordance with para. 5.5.1.

Step 4. Conduct initial checks in accordance with para. 5.5.2.

Step 5. Apply the sinusoidal acoustic test level and adjust its frequency to achieve the resonance condition, as indicated by the response from the control microphone, and adjust to the specified level, and apply for the specified time. If required, carry out inspections and performance checks in accordance with para. 5.5.2.

Step 6. Carry out the final inspection.

Step 7. Remove the test item from the chamber.

Step 8. In all cases record the information required.

6 FAILURE CRITERIA

The test item performance shall meet all appropriate specification requirements during and following the application of the acoustic test conditions.

ANNEX A

GUIDANCE FOR INITIAL TEST SEVERITY

When data are not available for the definition of service environment the following values may be used for initial design and testing.

1 BROAD BAND RANDOM AND INCIDENCE NOISE TESTING

1.1 Overall sound pressure level (OASPL)

From the known area of operation for the materiel the test overall sound pressure level and duration may be obtained from Table A1 below. The values have been developed from those in MIL-STD 810D.

1.2 Test spectrum

The applied test spectrum associated with these levels is shown in figure A1. The test spectrum should be achieved while maintaining the test parameters within the tolerances given in para.5.1

1.3 Simulation of aerodynamic turbulence

Where a broad band noise test is required for the simulation of aerodynamic turbulence, the test levels and durations should be derived in conjunction with those for the complementary mechanical test (ref Method 401 Annex A).

Table A1

Wide band levels and grazing incidence

TYPICAL APPLICATION	TEST LEVEL (OASPL) dB	DURATION (Min)
Transport aircraft,at locations not close to jet exhausts	130	30
Transport aircraft, in internal material bays close to jet exhausts	140	30
High performance aircraft at location not close to jet exhausts	140	30
High performance aircraft in internal material bays close to jet exhausts	150	30
Air-to-air missile on medium performance aircraft (q< 57456 Pa)	150	30
Air-to-ground missile on medium performance aircraft (q< 57456 Pa)	150	15
Ground material in enclosed engine runup areas	150	30
High performance aircraft,in internal material bays close to reheat exhaust and gun muzzles or in nose cones	160	30
Airborne rocket most locations but excluding booster or engine bays	160	8
Air-to-air missile on high performance aircraft (q< 86184 Pa)	165	30
Air-to-ground missile on high performance aircraft (q< 86184 Pa)	165	15
Airborne rocket booster or engine bays	165	8
Ground material on rocket launchers	165	8

2 CAVITY RESONANCE TESTING

2.1 Test parameters

For cavity resonance testing the sound pressure level B_o, frequencies f_N and duration T will be as calculated or defined in Table A2 below. The values have been developed from those in MIL-STD 810D.

Table A2

Cavity resonance test conditions

Test level $$B_0 = 20 \log(q) + 76.4\,\text{dB} \;\; (\text{ref } 20\ \mu\text{Pa})$$ $$f_n = \frac{6.13\,(N-0.25)\left(2.4-\frac{M^2}{2}\right)^{0.5}}{0.57\,(L)(C)+\left(2.4-\frac{M^2}{2}\right)^{0.5}}\ \text{Hz}$$ Test duration: T=1 hour per resonance frequency
Definitions f_N = Resonance frequency for the N^{th} mode (where N=1,2,3,..) up to 500 Hz (where f1>500 Hz use only this mode) N = Mode number C = Speed of sound at altitude of flight (m/s) L = Length/radius of opening exposed to air stream (m). A second set of resonance frequencies should be identified by using the distance parameter L as the depth of the cavity. M = Mach number q = Flight dynamic pressure when cavity is open (Pa)

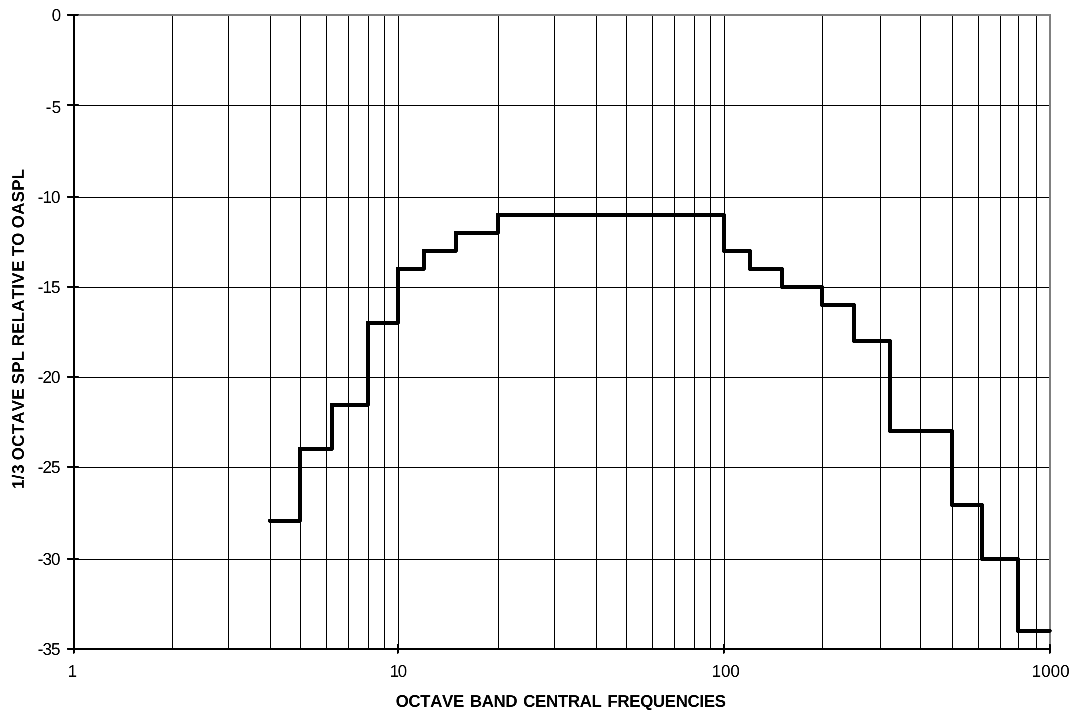


Figure A1- Applied Test Spectrum

Note: Overall test levels are given in Table 1

ANNEX B

ADDITIONAL TECHNICAL GUIDANCE

1 REVERBERATION CHAMBERS

A reverberation chamber is basically a cell with hard, acoustically reflective walls. When noise is generated in this room the multiple reflections within the main volume of the room cause a uniform diffuse noise field to be set up. The uniformity of this field is disturbed by three main effects.

a. At low frequencies standing modes are set up between parallel walls. The frequency below which these modes become significant is related to the chamber dimensions. Small chambers, below about 100 cubic metres in volume, are usually constructed so that no wall surfaces are parallel to each other in order to minimise this effect.

b. Reflections from the walls produce higher levels at the surface. The uniform noise field therefore only applies at positions within the central volume of the chamber and test items should not be positioned within about 0.5 metre of the walls.

c. The size of the test item can distort the noise field if the item is large relative to the volume of the chamber. It is normally recommended that the volume of the test item should not exceed 10% of the chamber volume.

Noise is normally generated with an air modulator and is injected into the chamber via a coupling horn. Provision is made in the chamber design to exhaust the air from the modulator through an acoustic attenuator in order to prevent the direct transmission of high intensity noise to areas outside the test chamber.

2 PROGRESSIVE WAVE TUBES

A parallel sided duct usually forms the working section of such a progressive noise facility. This may be circular or rectangular in section to suit the test requirements. For testing panels a rectangular section may be more suitable while an aircraft carried store may be more conveniently tested in a duct of circular section.

Noise is generated by an air modulator coupled into one end of the working section by a suitable horn. From the opposite end of the plain duct another horn couples the noise into an absorbing termination. Maximum absorption over the operating frequency range is required here order to minimise standing wave effects in the duct. Noise then progresses along the duct and is applied with grazing incidence over the surface of the test item.

The test item itself may be mounted within the duct in which case the grazing incidence wave will be applied over the whole of its external surface. Alternatively the test item may be mounted in the wall of the duct when the noise will be applied to only that surface within the duct, e.g. on one side of a panel. The method used will depend upon the test item and its in-service application.

3 ACOUSTIC NOISE CHARACTERISTICS

Radiated high intensity noise is subjected to distortion due to adiabatic heating. Thus, due to heating of the high pressure peaks and cooling of the rarefaction troughs, the local speed of propagation of these pressures are modified. This causes the peaks to travel faster and the troughs to travel slower than the local speed of propagation such that, at a distance from the source, a sinusoidal wave becomes triangular with a leading shock front.

This waveform is rich in harmonics and therefore the energy content is extended into a higher frequency range. It can be seen from this that it is not possible to produce a pure sinusoidal tone at high noise intensities.

The same effect takes place with high intensity random noise which is commonly produced by modulating an airflow with a valve driven by a dynamic actuator. This may be either electrodynamic or hydraulic in operation. Due to velocity and/or acceleration restraints on the actuator it is not possible to modulate the airflow at frequencies greater than about lkHz. Acoustic energy above this frequency, extending to 20 kHz or more, therefore results from a combination of cold air jet noise and harmonic distortion from this lower frequency modulation.

4 CONTROL STRATEGIES

Microphones are normally used to monitor and control the test condition. When testing stores and missiles it is recommended that not less than three microphones are used to control the test. Some test items may be more effectively monitored on their vibration response in which case the monitoring requirements of Method 401 should be followed as appropriate.

The monitoring system should be capable of measuring random noise with a peak to r.m.s. ratio of up to 3.0. Pressure calibrated microphones used in reverberation chambers should be corrected for random incidence noise while those used in progressive wave tubes should be corrected for free field grazing (90°) incidence noise and both should have a linear pressure response. Provision should be made for averaging the outputs of the microphones to provide the spatial average of the noise for control purposes.

5 DEFINITIONS

5.1 Sound Pressure Level:

The sound pressure level is the logarithmic ratio of the sound pressures expressed as:

$$Lp = 10\log\frac{I}{Io} = 20\log\frac{P}{Po}$$

where Io = reference intensity = 10^{-12} W.m^{-2} and

po = reference pressure = 20.10^{-6} Pa

Third Octave Filters:

The centre frequency, fo, of a third octave filter is:

$$f_0 = \sqrt{f_1 x f_2}$$

where f_1 = lower -3dB frequency and

f_2 = upper -3dB frequency

The relationships between the upper and lower -3dB frequencies are:

$$f_1 = \frac{f_0}{\sqrt[3]{2}}$$

$$f_2 = f_0 \sqrt[3]{2}$$

$$\frac{(f_2 - f_1)}{f_0} = 0.23$$

Standard third octave bands are defined in International Specification ISO 266.

For other definitions relevant to random vibration and data analysis refer to Method 401.

METHOD 403

CLASSICAL WAVEFORM SHOCK

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METHOD 403

CLASSICAL WAVEFORM SHOCK

1 SCOPE

1.1 Purpose

The purpose of this test method is to induce responses in systems, subsystems and units (hereafter called materiel) that are comparable with those likely to be experienced in-Service during the specified operational conditions, and that can be readily reproduced in the laboratory using appropriate shock test equipment. The basic intention is not necessarily to replicate the in-Service e nvironment.

1.2 Application

This test method is primarily designed to undertake shock testing involving the classical waveforms, such as the half-sine pulse, the final peak sawtooth pulse and the trapezoidal pulse. (Where they are required, descriptions of sho ck response spectra (SRS) for these classical waveforms are available in Method 417 Annex C.) Other time-based pulses can be accommodated by this test method, provided that they are within the capabilities of the shock test facility. However, Method 417, which addresses shock testing generally using electro-dynamic vibration generators, is preferred for time based pulses wherever practical, because of the improved reproducibility that can be attained. Complex shock responses, ie: those with many zero crossings, are addressed in Method 417. Moreover, if the test specification is produced in a SRS format, then Method 417 is recommended. For treatment of pyrotechnic shocks, Method 415 is recommended.

1.3 Limitations

This test method does not cover complex shock responses, or shocks described in a SRS format. Specifically this test method does not accommodate environments arising from gun blast, nuclear blast, pyrotechnic shock, underwater explosion, and safety drops.

As stated in Paragraph 1.1 classical waveform shock pulses do not necessarily replicate the shock environment experienced in-Service. Also, it may not be possible so simulate some actual operational in-Service shock environments because test machine and/or fixture limitations may preclude the satisfactory application of the specified pulse to the test item.

2 GUIDANCE

2.1 Effect of Environment

The following list is not intended to be all-inclusive but provides examples of problems that could occur when materiel responds to complex shock environments.

a. materiel electronic circuit card malfunction, electronic circuit card damage, electronic connector failure

b. changes in materiel dielectric strength, loss of insulation resistance, variations in magnetic and electrostatic field strength

c. permanent mechanical/structural deformation of the materiel as a result of overstress of materiel structural and non-structural members

d. collapse of mechanical elements of the materiel as a result of the ultimate strength of the component being exceeded

e. materiel failure as a result of increased or decreased friction between parts, or general interference between parts

f. fatiguing of materiel (low cycle fatigue)

g. intermittent electrical contacts

h. cracking and rupturing of materiel

2.2 Use of Measured Data

The use of measured data is not generally appropriate when using the Classical Waveform Shock method. If measured data are available, then Method 417 should be used wherever practical.

2.3 Sequence

The effect of shock induced stress may affect materiel performance under other environmental conditions, such as vibration, temperature, altitude, humidity, leakage or EMI/EMC. Also, it is essential that materiel which is likely to be sensitive to a combination of environments be tested to the relevant combinations simultaneously.

Where it is considered that a combined environment test is not essential or not practical to configure, and where it is required to evaluate the effects of shocks together with other environments, a single test item should be exposed to all relevant environmental conditions. The order of application of environmental tests should be compatible with the Service Life Cycle Environmental Profile.

2.4 Choice of Test Procedure

There is only one procedure for Classical Wave Form shock testing. The selection of test method is governed by many factors including the in-Service shock environment and materiel type. These and other factors are dealt with the General Requirements - AECTP 100 and in the environmental conditions - AECTP 200.

2.5 Types of Shock Simulation

The three classical pulses covered by this method are :

– half-sine

– terminal peak sawtooth

– trapezoidal

These pulses are described in Figures 1, 2 and 3 respectively.

For these three types of waveform, the severity is specified by a time domain pulse. The advantages of each pulse is given in Annex A, Paragraph 2.

2.6 Velocity Change

For many purposes, specifying the severity of the test by peak acceleration, pulse shape and duration is an adequate definition. Consequently, velocity change need not be specified except where it is necessary, either to achieve a high degree of reproducibility (for example, between repeat tests on production batches of equipment), or where there is a need to supplement or replace one of the normal parameters used to define the shock pulse. (For example, velocity change may be preferred to duration for shocks of high intensity and of extremely short duration.) The Environmental Test

Specification should, in these instances, invoke the velocity change requirement and specify the method of measurement.

Velocity change may be determined from the measured data by any of the following :

(a) From the impact velocity for shock pulses not involving rebound motion.

(b) By the drop and rebound height as appropriate, where free fall facilities are used.

(c) By integrating the acceleration pulse with respect to time between the limits of 0.4D before the start of the pulse to 0.1D beyond the pulse, where D is the duration of the ideal pulse.

2.7 Materiel Operation

The test item should be operated and its performance measured and noted as specified in the Test Instruction or relevant specification.

3 SEVERITIES

3.1 General

Initial test severities are to be found in Annex A. Where appropriate, these severities should be used in conjunction with the appropriate information given in AECTP 200. These severities should be considered as initial values until measured data is obtained, at which time, consideration should be given to undertaking any further tests using Method 417.

The number of shock pulses applied should be a minimum of three in both directions, along each of the three orthogonal axes, ie: a total of 18 shocks.

3.2 Supporting Assessment

It should be noted that the test pulse selected is unlikely to be an adequate simulation of the in-Service environment and consequently, a supporting assessment is usually necessary to complement the test results and justify the selected test rationale.

3.3 Isolation System

Materiel intended for use with shock isolation systems should normally be tested with its isolators in position. If it is not practicable to carry out the shock test with the appropriate isolators, or if the dynamic characteristics of the materiel installation are highly variable, then the test item should be tested without isolators at a modified severity specified in the Test Instruction.

3.4 Sub-System Testing

When identified in the test plan, sub-systems of the materiel may be tested separately and can be subjected to different shock severities. In this case the Test Instruction should stipulate the shock severities specific to each sub-system.

4 INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- The identification of the test item,
- The definition of the test item,

- The definition of the test severity including axes, duration and number of pulses to be applied,
- The type of test: development, qualification etc.,
- The method of mounting, including isolators if applicable,
- The operation or non-operation of test item during test,
- The packaging conditions, if applicable,
- The requirements for operating checks if applicable,
- The control strategy (pulse shape or velocity change),
- The details required to perform the test,
- The definition of the failure criteria if applicable.

4.2 If Required

- The climatic conditions, if other than standard laboratory conditions,
- The effect of gravity and the consequent precautions,
- The value of the tolerable spurious magnetic field,
- The tolerances, if different or additional to these in Paragraph 5.1.

5 TEST PROCEDURE

5.1 Tolerances

Tolerances for the classical waveforms are given in Figures 1, 2 and 3 respectively.

5.2 Installation Conditions of Test Item

Unless otherwise stated in the Test Instruction for the materiel, the following will apply :

- The test item shall be mechanically fastened to the shock machine, directly by its normal means of attachment, or by means of a fixture. The mounting configuration shall enable the test item to be subjected to shocks along the various axes and directions as specified. External connections necessary for measuring purposes should add minimum restraint and mass.
- Any additional stays or straps should be avoided. If cables, pipes, or other connections are required during the test, these should be arranged so as to add similar restraint and mass as in the Service installation.
- Materiel intended for use with isolators shall be tested with its isolators (see Paragraph 3.3.).
- The direction of gravity or any loading factors (mechanisms, shock isolators, etc) must be taken into account by compensation or by suitable simulation.

5.3 Adjustment

- The test apparatus should be adjusted to ensure that the required test parameters can be produced during the actual test. A dynamic representation of the test item should be used for this purpose. An actual test item can be used if low amplitude shocks are acceptable for this task, but only as a last resort due to the potential for materiel damage.

– Unless otherwise specified, the measurement instrumentation system shall conform with Figure 4.

5.4 Test Preparation

5.4.1 Pre-conditioning:

The test item should be stabilised to its initial climatic and other conditions as stipulated in the Test Instruction.

5.4.2 Operational Checks:

All operational checks including all examinations should be undertaken as stipulated in the Test Instruction.

The final operational checks should be made after the materiel has been returned to rest under pre-conditioning conditions and thermal stability has been obtained.

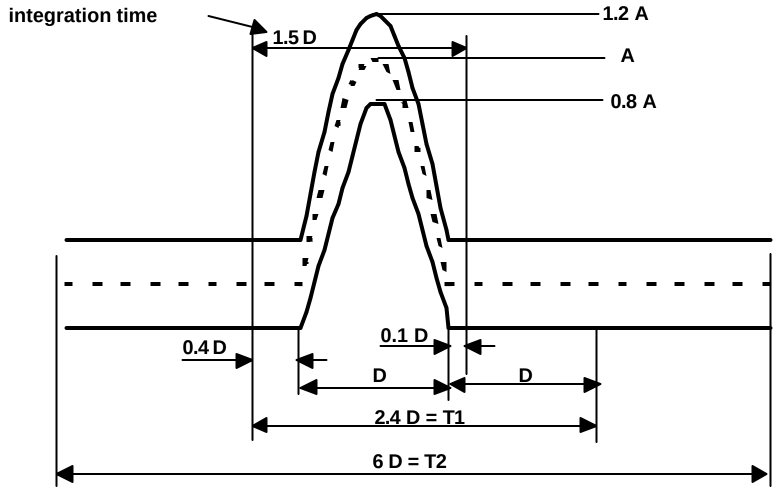


Figure 1: Half-sine pulse
(Refer to key under Figure 3)

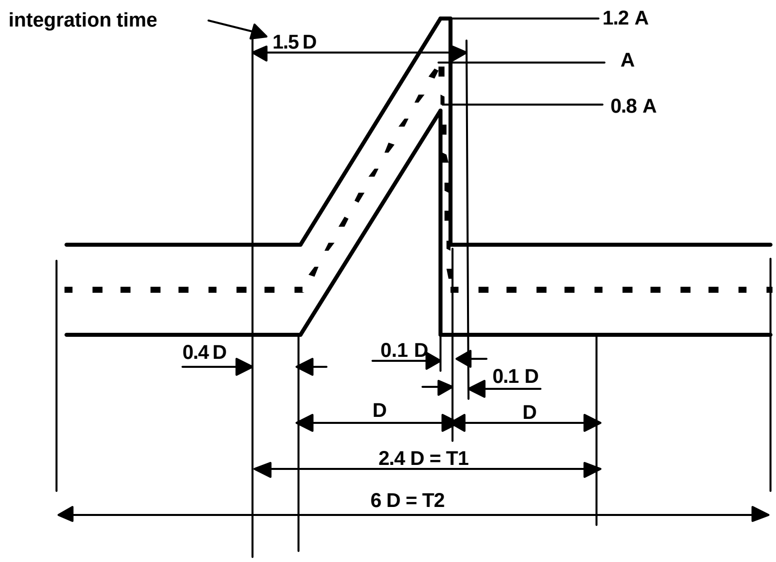


Figure 2: Final-peak sawtooth pulse
(Refer to key under Figure 3)

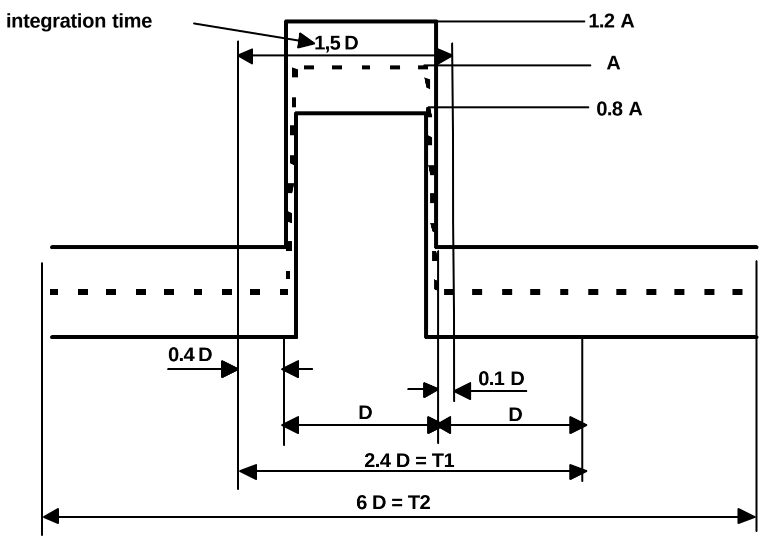
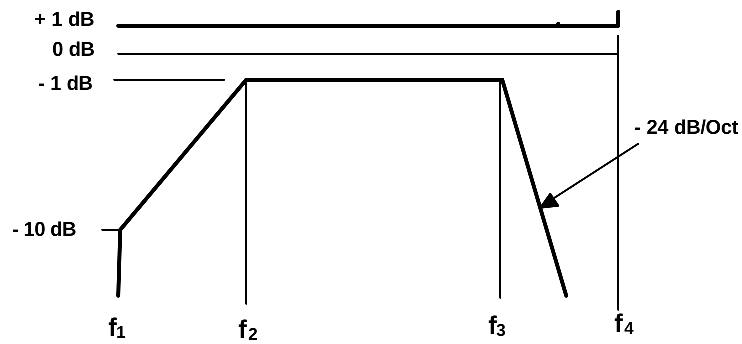


Figure 3: Trapezoidal pulse

Note: Key for figures 1, 2, and 3

	nominal pulse
	limits of tolerances
D	duration of nominal pulse
A	peak acceleration of nominal pulse
T_1	minimum time during which the pulse shall be monitored for shocks produced using a conventional shock testing machine
T_2	minimum time during which the pulse shall be monitored for shocks produced using a vibration generator



Duration of Pulse (ms)	Low frequency Cut off (Hz)		High frequency Cut Off (kHz)	Frequency at which response may rise above +1 dB (kHz)
	f_1	f_2	f_3	f_4
25	0.2	1	1	2
11	0.5	1	1	2
6	1	4	2	4
3	4	16	5	25
<3	4	16	15	25

NOTE 1 For shocks of duration less than 3 milliseconds the high frequency cut-off and +1dB response frequencies indicated may be inadequate if accurate measurement of the pulse shape is required. In such instances the relevant specification shall state the required frequencies of cut-off and the +1dB response.

NOTE 2 There should be no significant phase shift over the frequency range of the measuring system

Figure 4: Required frequency response of measurement instrumentation system, shock test

5.5 Procedures

Step 1. Select the test pulse or velocity change strategy, respecting the tolerances defined in Paragraph 5.1.

Step 2. Adjust the shock generator in accordance with Paragraph 5.3. The installation of a dynamic representation shall be in accordance with Paragraph 5.2. Make the settings necessary so as to obtain three consecutive shocks which meet the severity specified. Replace the dynamic representation with the real test item.

Step 3. Make the initial operational checks as per Paragraph 5.4.2.

Step 4. Apply the shock and record the data required to prove the validity of the test. For assemblies mounted on isolators, any bottoming or impact with the structure or adjacent assemblies should be noted.

Step 5. Make the final operating checks as per Paragraph 5.4.2.

Step 6. Repeat steps 1 to 5 as stipulated in the Test Instruction (see Annex A Table A.1).

6 FAILURE CRITERIA

The test item performance shall meet all appropriate specification requirements during and following the completion of the shock test series.

ANNEX A

GUIDANCE FOR INITIAL TEST SEVERITY

1 SCOPE

1.1 This annex is intended to provide the rationale behind the information contained in the preceding procedures and to give guidance for selecting pulse shape, peak acceleration, and duration, until the actual environment has been measured.

1.2 For general purposes, the final peak sawtooth has the advantage over the half-sine pulse shape of having a more uniform residual shock response spectrum This increases the likelihood that the specimen resonances will be excited and that the test can be reproduced. The half-sine pulse has application where the test is representing shock resulting from impact with, or retardation by, a predominantly linear elastic system. The shocks transmitted to materiel through its environment vary in both shape and amplitude and differ from classical pulse shapes (half-sine, sawtooth, trapezoidal, etc). These classical pulses do not exist in a real environment but are intended to approximate the typical shocks encountered in service and create materiel responses similar to those from the actual shock. The response of an item with many degrees of freedom depends upon both the shock input (shape and amplitude) and the characteristics of the materiel being tested (resonant frequencies, damping, non-linearities, and transmissibilities).

1.3 This test procedure will not be required along any axis for which a sufficiently severe random vibration test procedure is required, provided that materiel operational requirements are comparable.

SEVERITIES		PREFERRED PULSE SHAPE	APPLICATION
15 g	11 ms	Final Sawtooth	General test for robustness Structural integrity of mountings
30 g	18 ms	Final Sawtooth	Materiel installed or transported in a secured position on vehicles
40 g	11 ms	Final Sawtooth	Crash
100 g	6 ms	Final Sawtooth	High intensity shocks
			Rail Impact - Large Shipping Containers on Standard Rail Cars (Note 2)
39 g	18 ms	Half - Sine	Longitudinal
26 g	9 ms	Half - Sine	Vertical
			Rail Impact - Items Mounted Directly onto the Rail Car Body (including inside equipment cases) (Note 3)
5.1 g	30 ms	Half - Sine	Longitudinal
3.1 g	30 ms	Half - Sine	Vertical & transverse

Note 1 : A minimum of three shocks along each direction of the three orthogonal axes (18 shocks) should be applied.

Note 2 : Source : Sandia National Laboratories, Report number SAND 76-0427, Shocks and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks. The levels are representative of a severe impact environment for standard draft gear rail cars.

Note 3 : Source : IEC TC9 WG 21 Draft revision 1996 (9/1371) random Vibration and Shock Testing of Equipment for Use on Railway Vehicles. The levels are representative of rail impacts for cushioned coupler cars.

Table A.1: Initial Severities

ANNEX B

TECHNICAL GUIDANCE ON THE DERIVATION OF NON-CONVENTIONAL TEST WAVEFORMS

1 DEFINITION OF THE TEST WAVEFORM

1.1 General

Current facilities and techniques allow the derivation of test waveforms from measured and environmental data by several different methods. The most common approaches include the derivation of test waveforms from:

a. Direct capture of measured in-Service data

b. A shock response spectrum

c. Fitting of an analytically described waveform

1.2 Test Waveforms Derived from Analog Capture

The transient capture facility available on most computer based control systems may be used to acquire a transient waveform directly. However, the use of waveforms acquired by this approach may be limited by the following:

a. The requirements of the test waveform may be beyond the physical limitations of the generator in terms of either thrust, velocity or displacement

b. The statistical uncertainty associated with a single measured event

The first limitation can sometimes be resolved by modifying the test waveform to ensure that the generator velocity and displacement constraints are met. This is usually achieved by modulating the measured in-Service data with a low frequency waveform to ensure the final velocity and displacement are zero. The second limitation can be overcome if sufficient confidence can be achieved in the test data.

1.3 Test Waveforms Derived from a Shock Response Spectrum

Where measured data exist which relate to a particular shock environment, but which, due to complexity, are not suitable as test criteria, the derivation of a test waveform from a shock response spectrum may be appropriate. Unfortunately many test waveforms can be derived from a single specific shock response spectrum. As such due cognizance should be taken of the nature of the original time history. In these circumstances the derived waveform should always be agreed with the Test Specifier.

A suitable method of deriving a test waveform from a shock response spectrum is discussed below under Generation of Test Waveforms from Shock Response Spectra. The procedure is used to create a test waveform described as an analytical function. The derivation of shock response spectra from field data is also addressed in Determination of Shock Response Spectra from Field Data.

1.4 Test Waveforms Described by Analytical Functions

Where measured data exhibit a repeatable form in the time domain or are of a simplistic nature, it may be possible to fit a mathematical or analytical function to define the shock waveform. It may be necessary when using this approach to modulate the required waveform to ensure that the test waveform is within the physical capabilities of the vibration generator.

2 GENERATION OF TEST WAVEFORMS FROM SHOCK RESPONSE SPECTRA

2.1 The use of summations of oscillatory type pulses has been recognized as a possible method for representing certain types of shock environment. With the development of digital control techniques it is possible, by using these techniques to reproduce very complicated time histories.

2.2 Two types of oscillatory pulse have attained fairly widespread use. These are the decaying sinusoid, which has the form

$$A = A_o e^{-\zeta \omega t} \sin \omega \qquad \text{Equation 1}$$

and the wavelet type pulse which has the form

$$A = A_o \sin \omega t \sin \psi t \qquad \text{Equation 2}$$

Acceptable results may be obtained by using either of these methods. The approach, specifically considered here, is that using decaying sinusoids. However, the comments are largely applicable to both methods.

2.3 The basic procedure for deriving a suitable waveform from a specified shock response spectrum, illustrated in Figure B1, is as follows:

a. Firstly an initial estimate is made of the characteristics of the required waveform.

b. This estimate is then improved using an iterative procedure.

2.4 Obtaining initial estimates of the test waveform may be considered to have three aspects, namely the identification of the frequencies of the important sinusoidal components, the determination of the decay rate for each component and the determination of the amplitude of each decaying sinusoid.

2.5 For those shock response spectra which exhibit clearly identifiable peaks, the initial choice of frequency components is relatively straight forward. However, where no obvious peaks exist reference to the Fourier spectrum or Energy Spectral Density of the field data may provide an insight into a suitable choice of starting frequencies.

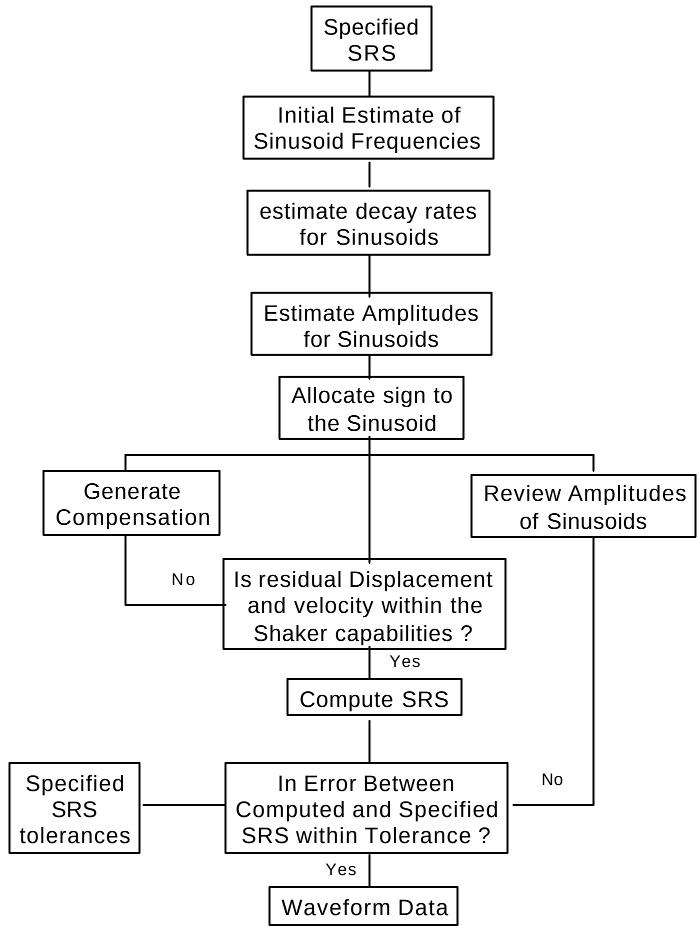


Figure B1. Generation of a test waveform from shock response spectrum.

2.6 The decay rate of each sinusoidal component may be determined from either inspection of the time response or its associated shock response spectra. Decay rates can be obtained from the time response using techniques such as logarithmic decrement. The shape of the SRS, as shown in Figure B2 can also aid the choice of decay rates.

2.7 The amplitudes of the sinusoids can be determined from Figure B3. Figure B3 represents the normalized maximum response of a single degree of freedom system to a decaying sinusoidal input as a function of the decay rate of the sinusoid. The plot is for various levels of damping in the single degree of freedom system. Figure B4 is a plot of the inverse of Figure B3, that is the input level per unit maximum response of a single degree of freedom system with 5% damping. The amplitude of the sinusoidal component may therefore be determined by multiplying the value of the test shock response spectrum at the frequency of the decaying sinusoid by the input level corresponding to the appropriate decay rate from Figure B4.

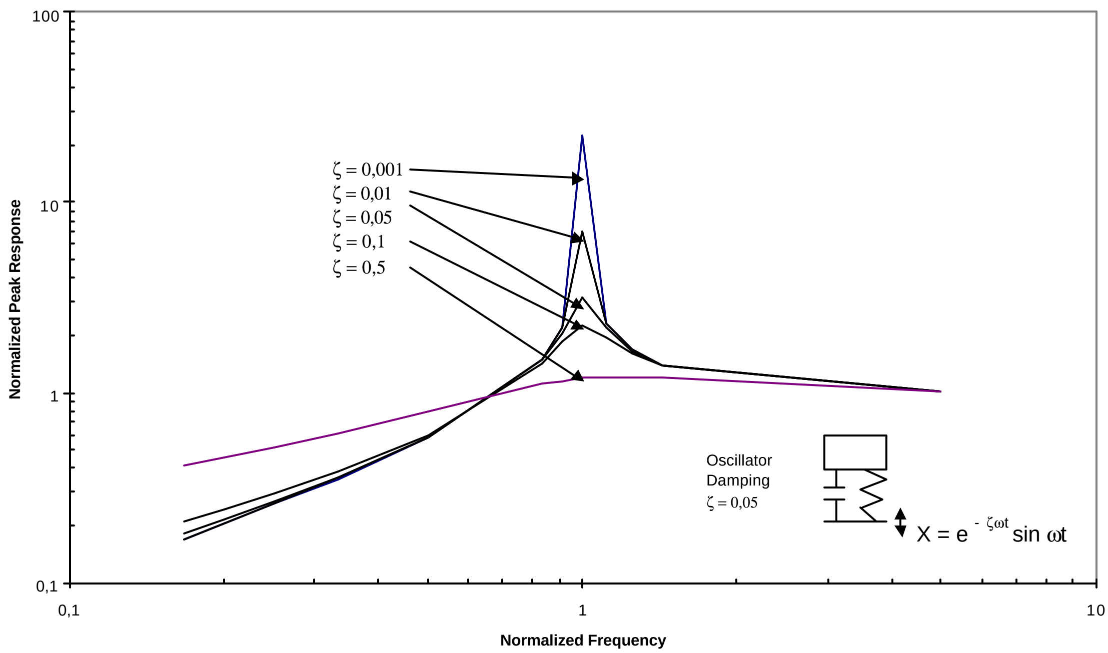


Figure B2. Normalized maximum response.

2.8 The sign of the amplitude of the sinusoidal components may be either positive or negative. The choice of sign does not have an effect on the shock response spectrum of the composite waveform. If the spectrum contains discrete peaks then a superposition of in-phase waveforms will accentuate the peaks and valleys in the spectrum. If, however, the spectrum is without marked peaks the synthesis of component waveforms combined alternatively in and our of phase will tend to smooth the spectrum.

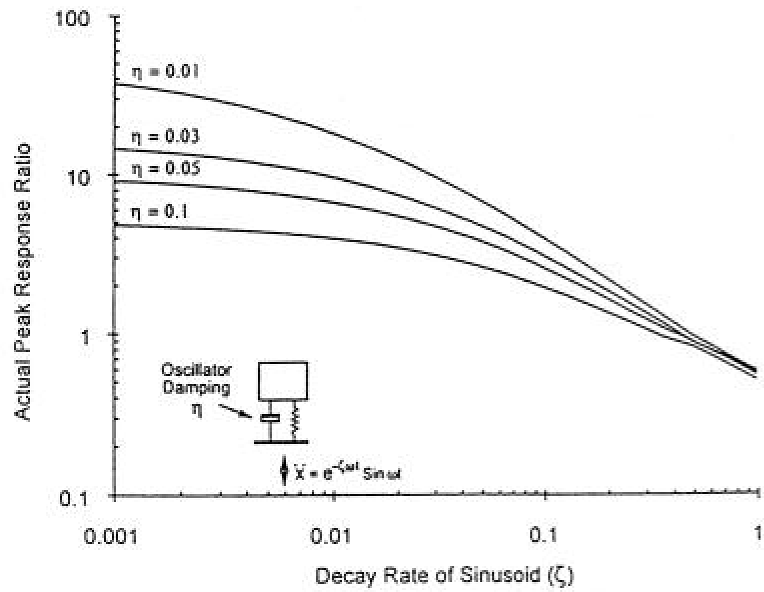


Figure B3. Response per unit imput

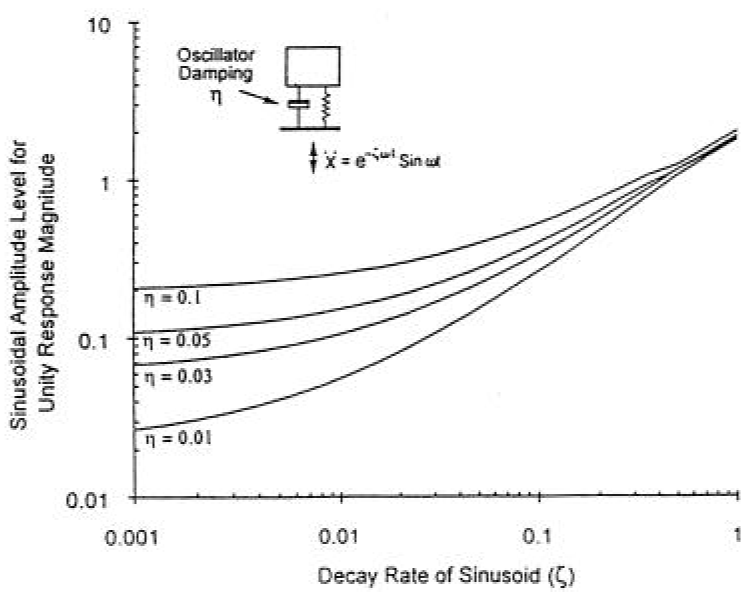


Figure B4. Input per unit response.

2.9 An important point to note is that the final velocity and displacement of the derived waveform may not zero. In order to overcome potential problems with the vibrator a compensation pulse is normally added to the synthesized time history. In some proprietary shock synthesis programs this compensation pulse is added without user intervention. However, in others compensation pulse frequency and decay rate must be selected. Generally, a compensation pulse should be applied with a frequency of approximately one-half to one-third the minimum frequency in the shock response spectrum with a decay rate approaching 100% of critical damping. Using suitable values of compensation pulse frequency (ω_m) and decay rate (ζ_m) the compensation pulse amplitude (A_m) and delay time (t) can be computed (using Equations 3 and 4) to control residual velocity and displacement respectively. In this case the delay time is that between initiation of the compensation pulse and the subsequent start of the decaying sinusoids.

$$\frac{A_m}{\omega_m\left(\zeta_m^2+1\right)}=-\sum_{i=1}^{n}\frac{A_i}{\omega_i\left(\zeta_i^2+1\right)} \qquad \text{Equation 3}$$

$$\frac{A_m\pi}{\omega_m\left(\zeta_m^2+1\right)}=\frac{2\zeta_m A_m}{\omega_m^2\left(\zeta_m^2+1\right)^2}+\sum_{i=1}^{n}\frac{2\zeta_m A_m}{\omega_i^2\left(\zeta_i^2+1\right)^2} \qquad \text{Equation 4}$$

A_i, ω_i, ζ_i are the amplitude, cyclic frequency and decay rate of the ith sinusoidal component.

2.10 It is important to note that the above procedure will develop a shock response spectrum based on the assumption that the individual sinusoidal components act independently. An iteration process is then required whereby component amplitudes and decay rates are varied to obtain a better fit to the shock response spectrum. This procedure is, in general, built into proprietary shock synthesis computer programs.

3 THE DETERMINATION OF SHOCK RESPONSE SPECTRA FROM FIELD DATA

3.1 This section gives guidelines for the generation of shock response spectra from field data. In general each axis of the field data for a specific location will have a different shock response spectrum.

3.2 The shock response spectra required for the determination of the test shock response spectrum will be obtained from reduction of the measured time histories of the transient event.

3.3 The duration of the shock input time history used for the response spectrum calculation should be twice the effective pulse duration starting at a time to include the most significant data prior to and/or following the effective duration.

3.4 The shock response spectra analysis parameters, damping, frequency interval and frequency range, should be selected from consideration of the shock waveform and the equipment to be tested. However, useful starting values are for a damping ratio of 5% of critical damping (Q = 10) at a sequence of resonator frequencies at intervals of 1/6th octave or smaller to span at least 5 Hz to 2,000 Hz.

3.5 The spectrum used to define the test shock response spectrum should be a composite of positive and negative directions commonly called the maximax spectrum. It should be the maximum value obtained from both the primary and residual responses.

3.6 When a sufficient number of spectra is available an appropriate statistical basis should be employed to determine the required test shock response spectrum. Guidance for such statistical analysis is found in Annex D.

3.7 As a general guide for the classical waveform shock type of test, use of 95.5% population limits is usually applicable for most applications. However, for certain types of test (notably function and reliability assessment) the use of smaller population limits (typically 68.3%) may be more appropriate. For some safety demonstration testing population limits of 99.7% or greater may be required. For some material the design requirements may specify alternative values to be adopted. Selection of these population limits must be consistent with the statistical procedures employed in Annex D.

3.8 When insufficient data are available for statistical analysis (the use of the above guidance becomes suspect for less than five samples) an increase over the maximum available spectral data should be used to establish the required test spectrum in order to account for variability of the environment.

ANNEX C

TECHNICAL GUIDANCE ON THE PERFORMANCES OF SHOCK TESTS

1 SCOPE

This annex is intended to provide guidance and definitions that will be useful in setting up and performing shock tests. It is not intended to be a textbook on shock.

2 LIMITATIONS

Shock testing can be performed on test apparatus designed specifically for this purpose. Alternatively, it may be possible to use a vibration generator, within certain mechanical and electrical limitations. This annex applies only to shakers.

2.1 Displacement

The specification defines, either through the wave form or through the shock response spectrum, the maximum acceleration to be reached in a given time. This results in a transient displacement whose instantaneous value should remain within the limits of the generator. Generally speaking conventional wave forms require larger displacements than the shock response spectra simulated by oscillatory transients.

2.1.1 Electrodynamic Shakers

These shakers are normal vibration test shakers, usually with a 100g armature acceleration limit and either a maximum stroke of 25 mm (1 inch) or, with some later machines, 50 mm (2 inches). Some shock testing is possible within the limitations above and the pre and post pulse deviations permitted by the test instruction. The position of the neutral of the coil can be set to take into account possible dissymetries in the transient displacement. Overtravel of the armature at shock test energy levels can severely damage the shaker.

2.1.2 Electrohydraulic Shakers

The use of suitable electrohydraulic shakers for classical pulse shock testing circumvents the major limitation of electrodynamic shakers of limited displacement. The major limitation of electrohydraulic shakers is of frequency response although advanced systems are capable of 1 kHz. Their load, therefore acceleration, capability often exceeds that of the electrodynamic types available.

2.2 Velocity

2.2.1 Electrodynamic Shaker Velocity Limitations

The maximum velocity of these shakers is limited by the acceleration and displacement limits imposed by system electrical and mechanical design parameters.

2.2.2 Electrohydraulic Shaker Velocity Limitations

Velocity limitations are a result of hydraulic flow restrictions and vary from system to system. Systems designed for this type of testing may have parallel servo valves and hydraulic accumulators which gives wider limits on velocity and frequency bandwidth.

2.3 Acceleration

2.3.1 Electrodynamic Shaker Acceleration Limitations

Acceleration is limited by the amount of electrical power that can be fed through the armature, the mechanical strength of the armature and table assembly, its total load including self mass and internal losses and the mechanical and electrical impedances of the test system and load. It should be noted that the mechanical impedance term, above, includes anti-resonance effects in the frequency domain which can absorb a disproportionate amount of the available power.

2.3.2 Electrohydraulic Shaker Acceleration Limitations

Since, within other limitations of these shakers, tests can be controlled by a displacement/time or force/time method the effects of test item anti-resonances play a much less important role within the test. Since these shakers are self stopping when the servo valves dose there is much less chance of system over-run damage and therefore higher accelerations can be safely achieved.

2.4 Frequency Range

Electrodynamic test systems operate in a higher frequency band than their electrohydraulic counterparts.

2.4.1 Electrodynamic Shaker Frequency Range

The useful frequency range of these shakers is severely limited at low frequencies by their amplitude limitation and at high frequencies by modal density. Modal density of the test item, its support assembly and of the shaker head and armature dictates that energy absorbent anti-resonances will be present in sufficient magnitude to account for any reasonable available power when driving from a frequency response function oriented pulse shaping controller, as most current shaker shock controllers are.

2.4.2 Electrohydraulic Shaker Frequency Range

There is little limitation at the low frequency end of the spectrum other than dictated by the pressure and flow characteristics of the system, the available stroke and mechanical strength. At high frequencies there is a finite limit related to the mass/stiffness of both the hydraulic medium and the servo valve operating speed. The effects of this are minimized in high performance systems by using parallel accumulators and servos with short hydraulic column lengths between accumulator and ram.

2.5 Power Amplifier

2.5.1 Electrodynamic Shaker Power Amplifier

The combination of instantaneous voltage and output current values (e and i) necessary is limited and depends on the construction of the amplifier, tube or solid circuit type.

2.5.2 Electrohydraulic Shaker Power System

Since, when used for shock testing, This type of shaker does not normally draw its power directly from a hydraulic line it only requires sufficient power to recharge its accumulators to the required pressure in a sufficiently short time commensurate with being ready to perform the next required shock. Where the shaker runs from a hydraulic main pressure system serving a whole test facility it is necessary to use local accumulators when shock testing to minimize line pressure fluctuations.

3 WAVE FORM SHOCK GENERATION

3.1 Generalities

During an actual shock test, the materiel is always at rest before and after the total shock time history, therefore the change in total velocity is zero. This fact dictates the need to precede and/or follow the specified pulse with additional pulses. These pre-and post pulses must be chosen such that, without changing the result of the test, they accumulate and/or dissipate energy in such a way as to zero both initial and final velocity.

Example in case of a true half sine:

$$0 \le t \le D$$

$$a(t) = A \sin\left(\frac{\pi t}{D}\right)$$

$$v(t) = -\frac{D\,A}{\pi} \cos\left(\frac{\pi t}{D}\right)$$

when t = 0,

$$v(t) = -\frac{D\,A}{\pi} \neq 0$$

when t = D,

$$v(t) = \frac{D\,A}{\pi} \neq 0$$

3.2 Case of Half Sine

In practice, we may use one on three different types of "half sine":

- Impulse (half sine with post-pulse)
- Impact with perfect rebound (half sine with post- and pre-pulse) or shock with over turning
- Impact without rebound (half sine with pre-pulse)

In the following, we will study only the first two, which are the most used.

The computation below is made for a semi-sinusoidal shock. The same method can be applied for other wave forms.

3.2.1 Impulse

From 0 to D, we obtain:

$$a(t) = A\sin wt\left(w = \frac{p}{D}\right)$$

$$v(t) = -\frac{A}{w}(\cos wt - 1)\ \text{initial conditions}\ : v(0) = 0$$

$$d(t) = \frac{A}{w}\left(t - \frac{\sin wt}{w},\right)\ ,\quad \text{for}\ t = 0,\ d(t) = 0$$

From D to t_1, we obtain:

$$a(t) = -pA$$

the total duration is

$$t_1 = D\left(1 + \frac{2}{pp}\right)$$

$$v(t) = -pA(t - D) + 2\frac{A}{w},\text{initial conditions}\ v(t_1) = 0$$

we have the continuity for the displacement to t = D, then:

$$d(t) = -pA\frac{t^2}{2} + At\left(Dp + \frac{2}{\omega}\right) - AD\left(\frac{1}{\omega} + D\frac{p}{2}\right)$$

we find the maximum displacement for $t = t_1$

$$d_{max} = p\frac{A}{2}\left(\left(\frac{2}{p\omega}\right)^2 - D^2\right)$$

If the relative masses of the moving part (M_m) and of the body (M_c) of the exciter are taken into account the value of the acceleration becomes:

$$G = \frac{A}{g_n + \left(1 + \frac{M_m}{M_c}\right)}$$

(Only if M_m is an inert mass without dampers)

3.2.2 Impact With Rebound

From 0 to t_1

a(t) = -pA

v(t) = -pAt (when t = 0, v(t) = 0)

d(t) = -pAt^2/2 (when t = 0, d(t) = 0)

Between t_1 and t_2

$a(t) = A \sin \omega(t-t_1)$, with $t_2 - t_1 = D$, and $\omega = \pi/D$

the equality of the acceleration curve area produces:

$t_1 p = 1/\omega$

$v(t) = -A/\omega \cos \omega(t - t_1) + cte$

the velocity should be zero with: $\omega t = \pi/2$

then: $v(t) = -\frac{A}{\omega} \cos \omega(t - t_1)$

$$d(t) = -\frac{A}{\omega^2} \sin \omega(t - t_2) + cte$$

we should have for $t = t_1$:

$$d(t) = -\frac{A}{\omega^2}\left(\sin \omega(t - t_2) + \frac{1}{2p}\right)$$

the displacement becomes maximum when $\omega t = \pi/2$

$$d_{max} = \frac{A}{\omega^2}\left(1 + \frac{1}{2p}\right)$$

From t_2 to t_3

$$t_3 = t_1 + t_2 = D\left(1 + \frac{2}{\pi p}\right)$$, the total duration is t_3, $D = t_2 - t_1$

$a(t) = -pA$

$v(t) = -pA(t - t_2) + cte$, $v(t_3) = 0$

then $v(t) = A\left(p(D - t) + \frac{2}{\omega}\right)$

$$d(t) = At\left(p\left(D - \frac{t}{2}\right) + \frac{2}{w}\right) + cte$$

when $t = t_3$, $d(t) = 0$

then:

$$d(t) = A\,t\left(p\left(D - \frac{t}{2}\right) + \frac{2}{\omega}\right) - \frac{A\,p}{2}\left(D + \frac{2}{p\omega}\right)^2$$

If the relative masses of the moving part (M_m) and of the body (M_c) of the exciter are taken into account, the value of the acceleration becomes:

$$G = \frac{A}{g_n + \left(1 + \frac{M_m}{M_c}\right)}$$

(Only, if M_m is an inert mass without dampers)

3.2.3 Conclusion

The maximum displacement compared with the rest position before the shock is at least four time weaker for impact with rebound than for impulse. This fraction is two for velocity.

Thus, "1/2 sine" shock tests are usually applied using the method of impact with rebound. This is of particular advantage when a shock test is performed on a vibration generator. Adjustment of the test apparatus to deliver the specified pulse should be with dynamic representation of the test item. This is because response of the test item will affect the pulse delivered by the test apparatus. The ratio of the mass of The test item to that of The test table should be sufficiently small to ensure that waveform distortion does not exceed tolerance limits, if the test apparatus does not incorporate means to compensate for distortion. When testing with the shock response spectrum method and especially when testing with methods which add pre-and/or post-pulses to the specified pulse, if the test item incorporates shock isolators, validity of the relative motion within The isolators should be confirmed during adjustment of the test apparatus.

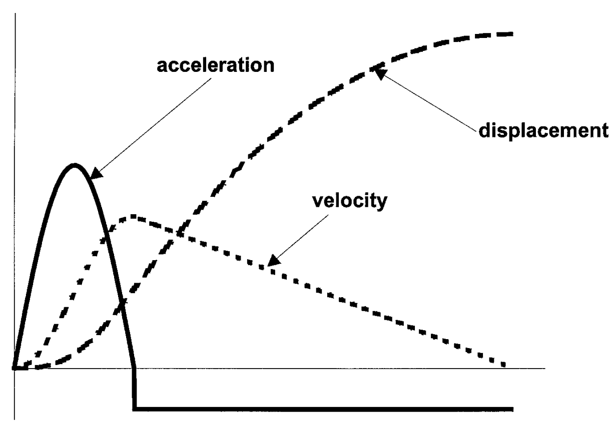


Figure C3.1. Form of Signals (Impulse).

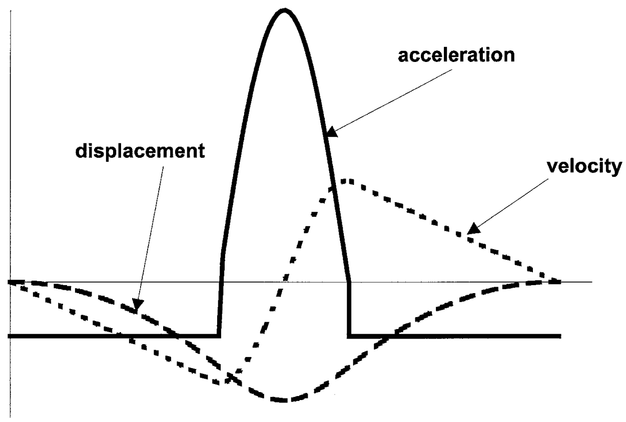


Figure C3.2. Form of Signals (Impact With Rebound).

4 SHOCK GENERATION WITH SHOCK RESPONSE SPECTRUM

As different wave forms correspond to the same shock response spectrum, a specification in the form of a shock response spectrum is less restrictive for the vibration generator and it is possible, for a given maximum acceleration, to reduce the maximum velocity in view of the frequencies range f2f3 in figure 4, method 403, where the tolerance of ±20 percent must be respected.

5 CHARACTERISTICS OF THE SHOCK RESPONSE SPECTRA

5.1 Definitions

The shock response spectrum is the envelope of the maximum response of undamped second degree linear systems, when their natural frequency fn varies.

The response parameter can be: (see Figure C4).

- either the maximum relative displacement of the mass in relation to the base (maximum of z)
- or the absolute maximum velocity of the mass (maximum of $\dot{y}$)
- or the absolute maximum acceleration of the m ass (maximum of $\ddot{y}$)

$$\omega_n = 2\pi f_n = \sqrt{\frac{k}{m}} \qquad \zeta = \frac{c}{2\sqrt{km}}$$

$$Q = \frac{1}{2\zeta_n} = \frac{\sqrt{km}}{c}$$

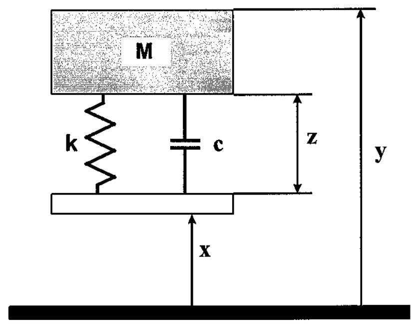


Figure C4. Linear System of a Single Degree of Freedom.

The relative displacement is more correctly linked to the constraints (damage potential), the velocity to the energy, the absolute acceleration to the forces (destructive potential) due to the shock. The balance of forces applied to the system with one degree of freedom in Figure 1 shows the differential equation of the movement:

$$m\ddot{y} + c(\dot{y} - \dot{x}) + k(y - x) = 0$$

By differentiating this equation once, twice and reducing it to the relative displacement, we obtain the following three equations:

$$\frac{d^2\dot{y}}{dt^2} + 2x_n w_n \frac{d\dot{y}}{dt} + w_n^2 \dot{y} = 2x_n w_n \frac{d\dot{x}}{dt} + w_n^2 \dot{x} = 2x_n w_n \ddot{x} + w_n^2 \dot{x}$$

$$\frac{d^2\ddot{y}}{dt^2} + 2x_n w_n \frac{d\ddot{y}}{dt} + w_n^2 \ddot{y} = 2x_n w_n \frac{d\ddot{x}}{dt} + w_n^2 \ddot{x}$$

$$\ddot{z} + 2x_n w_n \dot{z} + w_n^2 z = -\ddot{x}$$

The comparison between equations (3) and (4) shows that, if the systems with one degree of freedom are not damped (?n = 0) the shock response spectrum of the absolute accelerations is obtained by multiplying by -?n2 the shock response spectrum of the relative displacements.

The spectra are then identical, when they are rendered without dimensions by dividing:

- the absolute maximum acceleration of the mess $\ddot{y}_m$ by the maximum acceleration $\ddot{x}_m$ of the base, $\ddot{y}_m / \ddot{x}_m$
- the relative maximum displacement of the mass z_m by the relative maximum static displacement.

As long as the damping remains slight, Qn > 10, the standardized spectra of absolute accelerations and relative displacements can be considered as identical.

$$z_s = -\frac{m}{k}\ddot{x}_m = \frac{\ddot{x}_m}{w_n^2}; \frac{z_m}{z_s} = -w_n^2 \frac{z_m}{\ddot{x}_m}$$

Conversely the comparisons between equations (2) and (4) shows that, even in the case of an undamped system, the velocity response to the shock spectrum cannot be simply deduced from the relative displacement response to the shock spectrum given that if $\left|w_n^2 \dot{x}\right| = \left|w_n \ddot{x}\right|$ there is a phase shift of $\Pi/2$ between velocity and acceleration.

The velocity obtained by writing $w_n^2 \dot{x} = -w_n \ddot{x}$ in the equation (2) is referred to as "pseudo-velocity" (Z).

The pseudo velocity is equal to the relative velocity z in an undamped system.

These considerations involve defining:

- the shock response spectrum of the relative displacements, S_d
- the shock response spectrum of the relative velocities or "pseudo velocities", $S_v = \omega_n S_d$
- the shock response spectrum of the absolute accelerations $S_\gamma = -\omega_n^2 S_d$

These three spectra are identical, when they are standardized respectively by the relative displacement, the maximum pseudo-velocity and maximum acceleration, $z_s, \ddot{x}_m / w_n, \ddot{x}_m$ and when the damping of the systems with one degree of freedom remains slight ($Q_n > 10$).

The shock is only generally known from the time signal of the acceleration of the fasteners of the materiel to its carrier, $\ddot{x}(t)$, the control being made practical by accelerometers; the main purpose of the shock test is to test the robustness of the materiel, test it by the destructive potential of the shock linked to the absolute maximum acceleration.

Apart from special indications, the shock response spectrum is therefore that of the absolute accelerations.

Note: In the case in which the mechanical system cannot be modeled by differential equations of the second degree with constant coefficients, the concept of shock response spectrum is not applicable (e.g., when the wave length of the shock is not great versus the dimensions of the materiel involved).

5.2 Characteristics of the Shock Response Spectrum

The shock response spectrum consists of:

- a primary positive spectrum and a primary negative spectrum: a point of maximum positive and negative responses which occur during the time of the pulse form of the shock (the, positive direction is that of the acceleration $\ddot{x}(t)$ of the shock).
- a residual positive spectrum and a residual negative spectrum: point of maximum positive and negative responses which occur after the pulse duration of the shock; as long as damping remains slight ($Q_n > 10$), these two spectra are equal in absolute value.

The maximax shock response spectrum is the envelope of the absolute maximum values of these four spectra.

Generally speaking the materiel is not symmetrical, its resistance depends on the direction of application of the shock. A shock corresponding to real data is not simple and the absolute maximum values of the response can correspond to values both negative and positive. For this reason the shock with the maximax response spectrum is applied along each direction.

Note: The shock response spectrum specified in control is therefore the maximax spectrum of the absolute accelerations.

The residual shock response spectrum of accelerations $AR(\omega_n)$ is linked to the absolute value of the Fourier spectra of the shock $|F(\omega_n)|$, when the damping of the systems at one degree of freedom is zero.

If $|F(\omega_n)|$ is the Fourier transform modulus of the shock's acceleration time signal the relation is:

$$|F(\omega_n)| = \frac{A_R(\omega_n)}{\omega_n}$$

In this relation $|F(\omega_n|$ has the dimensions of a velocity, i.e., of an acceleration by rad/s.

The spectra of all the shocks with the same pulse form can be standardized in relation to the peak value of the acceleration A and to the duration D of the pulse: the coordinates scales are:

- ordinate a_{max} / A
- abscissa $f_n D$ or $2 \pi f_n D$

5.3 Description of Shock Response Spectra of Nominal Pulses

5.3.1 In the Case of Slight Damping ($Q_n > 10$)

Figure C5 shows the positive shock response spectra for the accelerations for the three types of pulse: final point sawtooth, half-sine, trapezoidal.

In the low frequency range up to $f_n D = 0.4$ the envelope is provided by the residual spectra and the response is in proportion to the velocity change of the pulse: meaning to say that the maximum response is more or less pulsive and approximately the same as that due to a Dirac pulse function whose velocity change is that of the area of the time form of the acceleration shock.

In the range of intermediate frequencies $0.4 < f_n D < 1$.

The primary spectra offer differences in level which depend on the pulse rise time. The final point sawtooth which has the greatest rise time has the lowest response with a given pulse peak value. The trapezoidal pulse has the highest response owing to the very short rise time and the peak plateau.

For higher frequencies $f_n D > 5/2$.

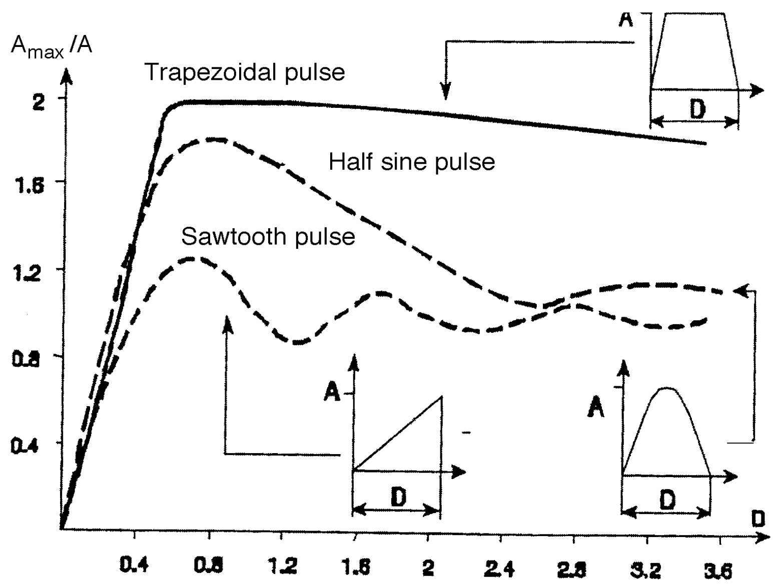


Figure C5. Positive SRS.

In all cases the response remains more or less constant: static area.

Figure C6 shows the primary (thick lines) and residual (fine lines) shock response spectra of the three types of pulses, and a nonzerodescent time for the sawtooth pulse.

The half-sine pulse has a practically nonexistent negative primary spectrum, in the same way as the trapezoidal pulse. This spectrum does not exist for the final point sawtooth pulse.

For the half-sine and trapezoidal pulses, only the positive residual spectra are shown in Figure C6. These spectra have periodically zero values due to the symmetry of the pulse wave. In return this drawback disappears with the sawtooth for which the positive residual spectrum is more or less merged for f_n > 0.5, with the primary spectrum. For a zero descent time, the negative residual spectrum is merged in absolute value with the positive residual spectrum. The effect of a nonzero descent time drops this spectrum below f_nD > 5 with alternating zero values.

The influence of the damping coefficient, slight with Q_n > 10, is more important on the negative spectra.

5.4 Effect of Ripples

Oscillatory systems with little damping are highly sensitive to ripples superimposed on the pulse.

To take an example the effects produced on the shock response spectrum of the half-sine are indicated in Figure C7.

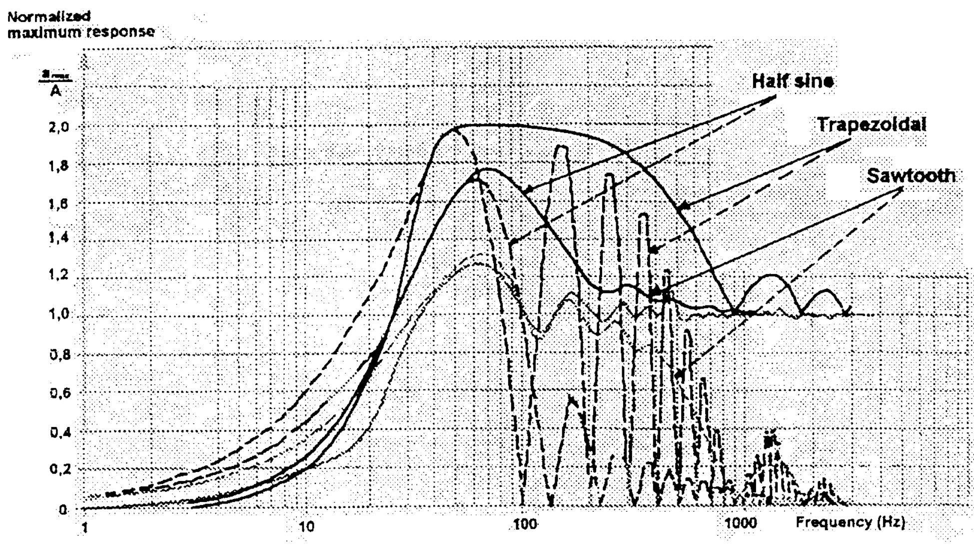


Figure C6. Primary (Thick Lines) and Residual (Fine Line) SRS.

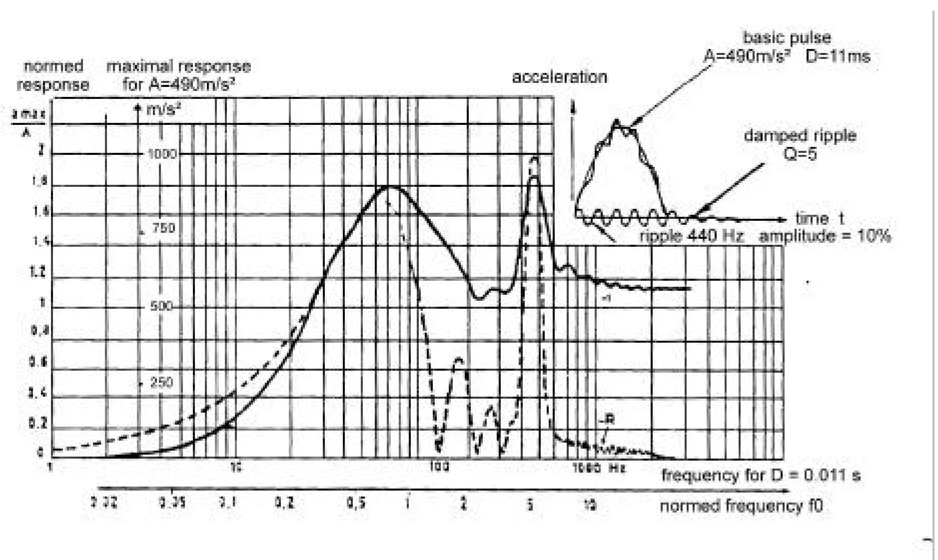


Figure C7. SRS of Half Sine Pulse With Ripple.

A ripple with an amplitude of 10 percent of that of the half-sine and frequency 460 Hz is superimposed on the pulse. The effect is considerable on the residual spectrum. Generally speaking as far as possible it is necessary to avoid ripples so as to preserve the reproducibility of the test.

The residual spectrum is very modified by weakly damped ripples which continue a long time after the nominal pulse.

5.5 Advantages of the Use of the Shock Response Spectrum Method in Comparison to Wave Form Method

- easier representation of the real environment
  - independence of the temporal signal
  - aids assessment of the risk of damage to the main modes
  - easier to specify (smoothing effect)
- easier reproducibility
  - an infinity of temporal signals can be used in particular standard wave form (ex: 1/2 sine pre/post pulses)
- for a simple model, calculation of the temporal response is easy(maximum acceleration is easier to find)
- allows comparison of the relative severities of different shocks synthesis of several shocks possible
- tolerances easier to use than on the temporal signal

5.6 Limits of the Use of the Response Spectrum Method in Comparison to Wave Form Method

- loss of the phase information and response modes recombination
  - loss of the time information, only with the temporal signal can we fully specify the shock limits and to analyze the good shock
- because the shock is not fully specified, significant errors are possible
- for one SRS we could find several shocks
- in real systems, which are more complex than simple models, we have coupling, nonlinearities, n degrees of freedom (divergence in comparison with the 1 d.o.f)
- SRS doesn't begin at f = 0 Hz and doesn't take into account the static aspect
- propagation phenomenon which restrict the use when the size of structure is not greater than the wavelength in the materiel

5.7 Cautionary Notes on the Use of the Response Spectrum Method

- it is difficult to determine the most suitable form of pre and/or post-pulses
- excessive distortion of the control system generating a transient which is not of the impulsive type
- a shock must not be replaced by a transient vibration unless its effects will be sufficiently similar

5.8 Use of Nominal Pulses

The terminal point sawtooth provides a better equivalence with the shock response spectrum but the effect of a nonnull time of return to zero is important on the negative spectrum. This is why this pulse must be applied in both directions.

The half-sine has a residual spectrum with periodical zero values, which can be a major drawback in certain cases.

The ripple effect can be considerable.

5.9 Systems With Several Degrees of Freedom

In order to be able to compute the shock response spectrum of a system with several degrees of freedom it is necessary to know how to schematize the action of the shock by a mate ix of generalized forces linked to the system's degrees of freedom. This schematization can be done in such a way as to enter these generalized forces in the form of acceleration at the materiel's fastening points to the carrier for example equations (1) and (3) in paragraph 5.1 in matrix writing with n degrees of freedom.

In the case in which the mass of materiel is large and entails considerable coupling with the support structure, the system to be analyzed should include a part of the support. To undertake such computations it is indispensable that the vibration tests should have supplied the frequency transfer function of the system from suitable excitation forces.

In most cases the specific modes of the system can be superimposed, decoupled and several shock response spectra can be computed for the damping values of the modes. With this procedure it is possible to enframe the specification of the test shock in such a way as not to overtest, when the real damping coefficient is less than the theoretical one employed, nor undertest in the opposite case.

6 GENERATION OF A SPECIFIED SHOCK

6.1 Shock Specified by Wave Form

6.1.1 Shock Machine

A specified wave form is obtained by adapting the programmer and the set up of the test item on the shock machine table. This adaptation depends on the type of machine used and is done experimentally with a ballasted mock-up of the test item.

6.1.2 Vibration Generators

6.1.2.1 Analog Assembly

The principle of control is provided by Figure C8.

The control chain includes:

- a programmable universal electrical pulse generator, with variable gain and adjustable pulse time, reproducing a pulse e(t) described by a set of time values
- a transfer function compensator; this (H_1) is adjustable by gain compensation devices in several frequency ranges and axial resonance frequency compensation devices

The transfer function (H2 of the amplifier-vibration-test item assembly and control chain is measured by applying either sinusoidal sweeping, or a pulse, or a white noise with a sufficient number of statistical degrees of freedom.

The compensator is set by progressive amplitudes in order for the output signal s(t) to be:

$$s(t) = H_1 \cdot H_2\ e(t) = k\ e(t)$$

$$H_1 = \frac{k}{H_2}$$

An analog set up becomes difficult to use when the transfer function H_2 can no longer be simulated by that of a decoupled system. Digital control is then used.

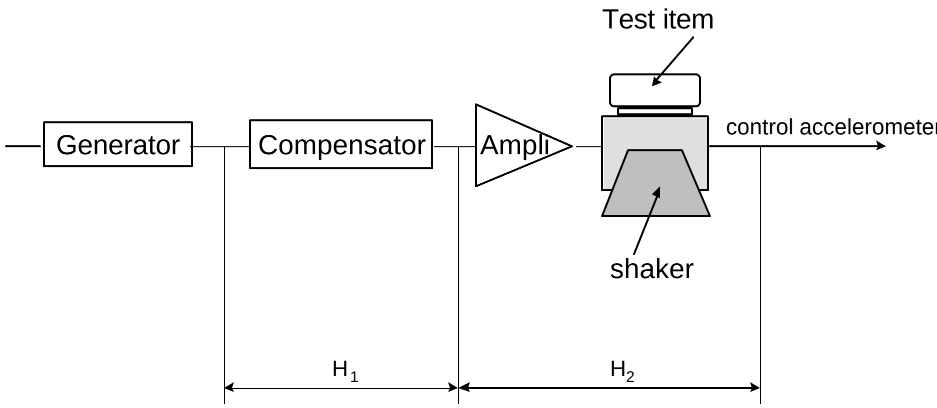


Figure C8. Analog Generation Set Up for the Wave Form Method.

6.1.2.2 Digital Set Up

The set up includes a universal computer programmed to adapt the reference input shock to the transfer function that may be symbolically written as $H_2(f) = s(f)/e(f)$ whose validity should be controlled by the coherence function between the output signal s(t) and the input signal e(t) if several pulses are averaged (otherwise the coherence function for one set of pulses is 1.0).

If:

$\overline{G_{11}(f)}$	direct Fourier transform of e(t)
$\overline{G_{22}(f)}$	direct Fourier transform of s(t)
$\overline{G_{12}(f)}$	cross Fourier transform between s(t) and e(t)
$\overline{G^{*}_{12}(f)}$	conjugate transfom of $G_{12}(f)$

$$H_2(f) = \frac{\overline{G_{22}(f)}}{\overline{G_{11}(f)}}$$

$$\mu(f) = \frac{\overline{G^{*}_{12}(f)}.\overline{G_{12}(f)}}{\overline{G_{11}(f)}.\overline{G22(f)}}$$

where $\tilde{\tilde{G}}_{ij}$ represents an estimated average over several pulses.

The input signal is corrected by reverse Fourier transform at progressive amplitudes.

The correction loo p can contain optimization programs depending on the specified wave form, and on the prepulse and post-pulse necessary to reduce the power required of the vibration generator while remaining within the specified tolerances of the wave form.

6.2 Specified Shock in the Form of a Shock Response Spectrum

6.2.1 Shock Machine

The only possibility is to generate the wave form whose shock response spectrum envelops as closely as possible, other the specified frequency range, the specified shock response spectrum. To do so certain rules based on the characteristics of the shock response spectrum are applied:

- the “static”' amplitude of the shock response spectrum at high frequencies provides the maximum acceleration of the wave form
- the pulse time of the wave form is provided by the abscissa of the first point which reaches the maximum acceleration of the wave form

The wave form obtainable closest to the one thus determined is adopted, preferably the terminal point sawtooth, whose shock response spectrum is best "filled" in each direction.

6.2.2 Vibration Generators

6.2.2.1 Analog Set Up

The principle of generation and control is shown in Figure C9.

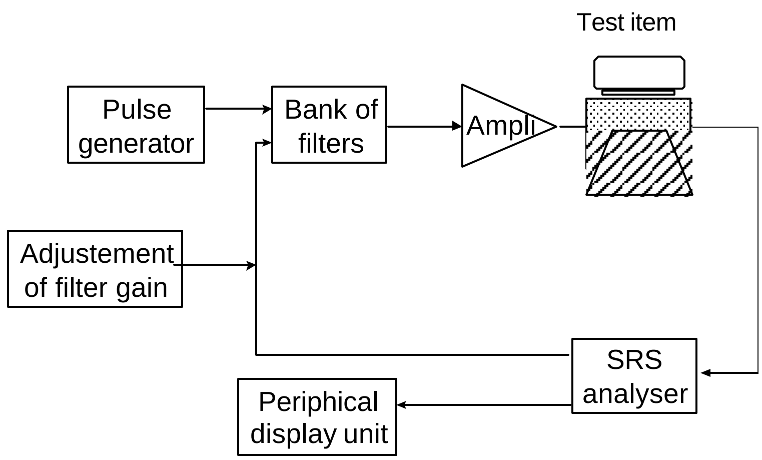


Figure C9. Analog Set Up for Shock Response Spectrum Generation.

6.2.2.2 Digital Set Up

Digital control consoles contain software which can synthesize a given shock response spectrum signal. The control console generates a set of transients, generally damped sinusoids of frequency f_n, logarithmic decrement n, and delay n, so that the shock response spectrum of each sinusoid coincides with that of the shock response spectrum specified at frequency f_n. The various parameters are adjusted contingent on the response spectrum obtained on output from the generator system, test item and accelerometric control chain, progressively in amplitude.

This adjustment may require a prior approach through successive approximations, relatively long to adjust.

The system can contain dosed loop control possibly with optimization

6.3 Test Setting Procedure

Figure C10 shows the diagram of the adjustment procedure required to generate the specified shock, either in wave form or in shock response spectrum, and depending on the operational area of the vibration generators amplifier (voltage e(t) and current i(t)).

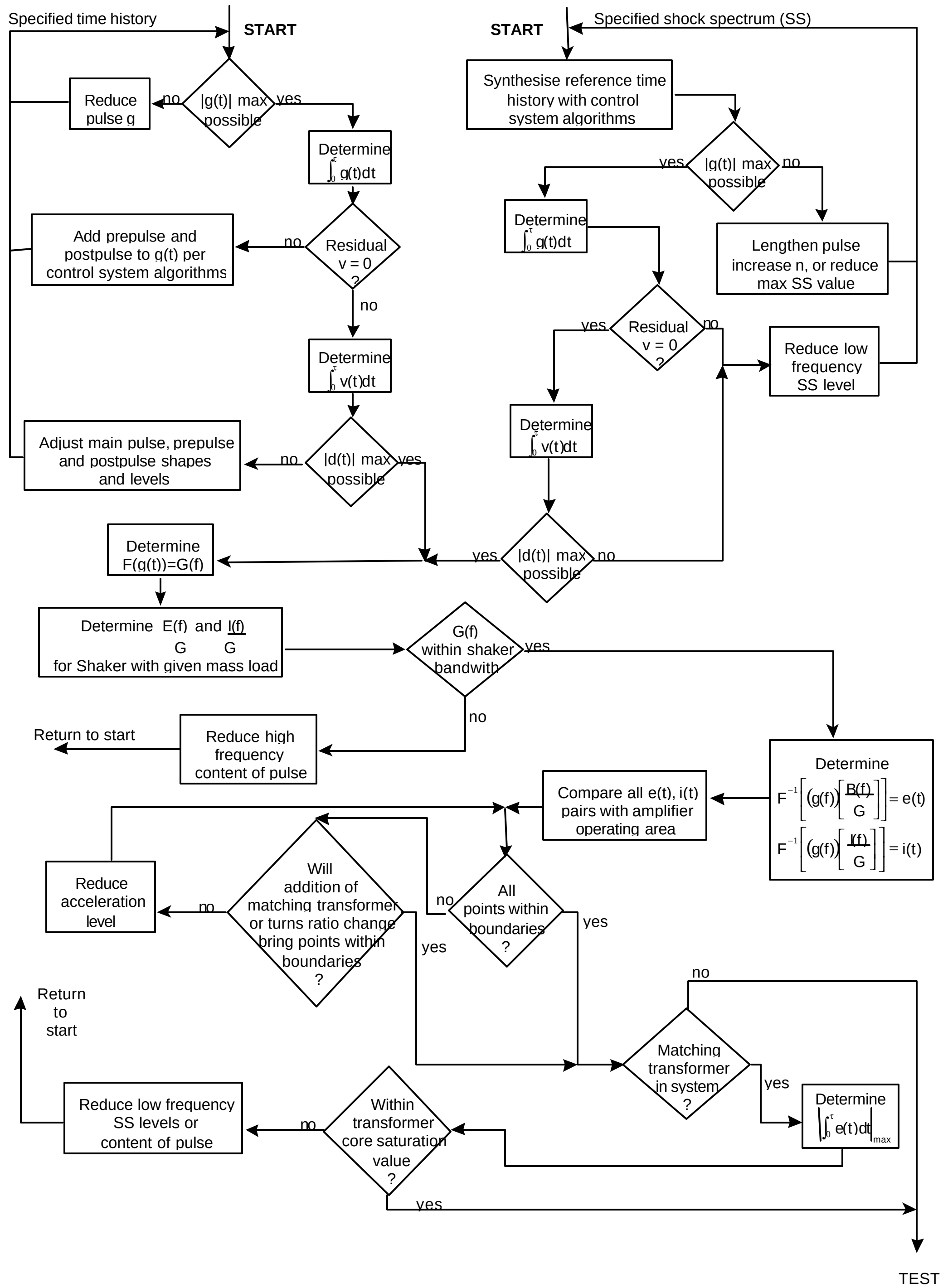


Figure C10. Procedure of adjustment diagram.

ANNEX D

STATISTICAL CONSIDERATIONS FOR DEVELOPING LIMITS ON PREDICTED AND PROCESSED DATA

(developed from MIL STD 810F)

1 SCOPE

1.1 Purpose

This Annex provides information relative to the statistical characterization of a set of data for the purpose of defining an envelope of the data set.

1.2 Application

Information in this Annex is generally applicable to frequency domain estimates that are either predicted based on given information or time domain environments processed in the frequency domain according to an appropriate technique i.e., for stationary random vibration the processing would be an ASD, for a very short transient the processing could be a SRS, ESD or FS. Given estimates in the frequency domain information in this Annex will allow the establishment of envelopes of the data in a statistically correct way.

2 DEVELOPMENT

2.1 Basic Estimate Assumptions

Combinations of prediction and measurement estimates may also be considered in the same manner. It is assumed here that uncertainty in individual measurement (processing error) does not effect the enveloping considerations. For measured field data digitally processed such that estimates of the SRS, ESD, FS or ASD are obtained for single sample records, it becomes useful to examine and summarize the overall statistics of "similar" estimates selected in a way so as to not bias the summary statistics. To ensure the estimates are not biased the measurement locations might be chosen randomly consistent with the measurement objectives. Similar estimated may be defined as (1) estimates at a single location on materiel that has been obtained from repeated testing under essentially identical experimental conditions, (2) estimates on a system that have been obtained from one test, where the estimates are taken (a) at several neighbouring locations displaying a degree of response homogeneity or (b) in "zones" i.e. points of similar response at varying locations, or (3) some combination of (1) and (2). It is assumed that there is a certain degree of homogeneity amongst the estimates across the frequency band of interest. This latter assumption generally requires that (1) the set of estimates for a given frequency have no significant "outliers" that can cause large variance estimates and (2) larger input stimulus to the system from which the measurements are taken implies larger estimate values.

2.2 Basic estimate summary pre-processing

There are two ways in which summary may be obtained. The first is to utilize an "enveloping" scheme on the basic estimates to arrive at a conservative estimate on the environment, and some qualitative estimate of the spread of basic estimates relative to this envelope. This procedure is dependent upon the judgment of the analyst and, in general, doe not provide consistent results among analysts. The second way is to combine the basic estimates in some statistically appropriate way and infer the statistical significance of the estimates based upon statistical distribution theory. Reference g summarizes the current state of knowledge relative to this approach and its relationship to enveloping.

In general, the estimates referred to and their statistics are related to the same frequency band over which the processing takes place. Unfortunately, for a given frequency band the statistics behind the overall set of estimates are not easily accessible because of the unknown distribution function of amplitudes for the frequency band of interest. In most cases the distribution function can be assumed to be normal if the individual estimates are transformed to a "normalizing" form by computing the logarithm to the base 10 of the estimate. For ESD, and FS estimates, the averaging of adjacent components (assumed to be statistically independent) increases the number of degree of freedom in the estimates while decreasing the frequency resolution with the possible introduction of statistical bias in the estimates. For ASD estimates, this also the case provided the bias error in the estimate is small, i.e., the resolution filter bandwidth is a very small fraction of the overall estimate bandwidth. For SRS estimates, because they are based on maximum response of a single-degree-of-freedom system as its natural frequency is varied, adjacent estimates tend to be statistically dependent and therefore not well smoothed with averaging filters unless the SRS is computed for very narrow frequency spacings. In such cases, smoothing of SRS estimates is better accomplished by reprocessing the original time history data at a broader natural frequency spacing, e.g., 1/6th octave as opposed to 1/12th octave. There is no apparent way to smooth dependent SRS estimates mathematically when reprocessing cannot be performed, and the acceptable alternative is some form of enveloping of the estimates. In any case, the larger the sample size the closer the logarithm transform of the estimates is to the normal distribution unless there is a measurement selection bias error in the experiment. Finally, it is important to note that generally the upper limit envelopes obtained in the paragraphs to follow, before application, are smoothed by straight line segments intersecting at spectrum "breakpoints". No guidance is provided in this Annex relative to this "smoothing" procedure e.g., whether estimates should be clipped or enveloped and the relationship of the bandwidth of the estimates to the degree of clipping, etc., except that such smoothing should be performed only by an experienced analyst. Reference g discusses this further.

2.3 Parametric Upper Limit Statistical Estimate Considerations.

In all the formulas for the estimate of the statistical upper limit of a set of N predictions or measurements,

$$\{X_1, X_2, ..., X_N\},$$

It is assumed that (1) the estimates will be logarithm transformed to bring the overall set of measurements closer to those sampled of a normal distribution and (2) the measurement selection bias error is negligible. Since the normal and “t” distribution are symmetric, the formulas below apply for the lower bound by changing the sign between the mean and the standard deviation quantity to minus. It is assumed here that all estimates are at a single frequency or for a single bandwidth, and that estimates among bandwidths are independent so that each bandwidth under consideration may be processed individually, and the results summarizes on one plot over the entire bandwidth as a function of frequency.

$$\text{For } \; y_i = \log_{10}(x_i)$$

$$i = 1, 2, \ldots, N$$

Mean estimate for true mean, μ_y is given by

$$m_y = \frac{1}{N}\sum_{i=1}^{N} y_i$$

and the unbiased estimate of the standard deviation for the true standard deviation σ_y is given by

$$s_y = \sqrt{\frac{\sum_{i=1}^{N}\left(y_i - m_y\right)^2}{N-1}}$$

2.3.1 NCL - Upper normal confidence limit.

The upper confidence interval limit on the true mean μ_y with a confidence coefficient of 1 - α (or confidence of 100 (1 - α)%) is given by

$$\mathrm{NCL}(N,\alpha) = 10^{m_y + \frac{S_y\, t_{N-1;\alpha}}{\sqrt{N}}}$$

where $t_{N-1;\alpha}$ is the α percentage point of the Student t distribution with N-1 degrees of freedom. NCL is termed the upper 100(1-α)% confidence limit on the true mean of the population from which the sample $\{X_1, X_2, ..., X_N\}$ was taken. NCL is included here for reference purposes and generally is not useful for establishing upper limits unless N > 50.

2.3.2 Upper normal one-sided tolerance limit.

The upper normal one-sided tolerance limit on the proportion β of population values that will be exceeded with a confidence coefficient (γ) by at least by NTL(N, β, γ) is given by

$$\mathrm{NTL}(N, \beta, \gamma) = 10^{m_y + s_y k_{N,\beta,\gamma}}$$

where $k_{N,\beta,\gamma}$ is the one-sided normal tolerance factor given in table D-1 for selected values of N, β and γ. NTL is termed the upper one-sided normal tolerance interval for which 100 β% of the values will lie below the limit with 100 γ% confidence. For β = 0.95 and γ = 0.50, this is referred to as the 95/50 limit.

The following table from reference g contains the k value N, β, γ. In general this method of estimation should not be used for small N with values of (β) and (γ) close to 1 since it is likely the assumption of the normality of the logarithm transform of the estimates will be violated. For N > 50, then N CL (N) = NTL (N, β, γ) for a = 1 - β and γ = 0.50.

2.3.3 NPL - Upper normal prediction limit.

The upper normal prediction limit is the value of x (for the original data set) that will exceed the next predicted or measured value with confidence coefficient γ, and is given by

$$\mathrm{NPL}(N,\gamma) = 10^{m_y + s_y \sqrt{1+\frac{1}{N}}\; t_{N-1;\alpha}}$$

where α = 1 - γ. $t_{N-1;\alpha}$ is the “Student” variable with N-1 degrees of freedom at the 100 α = 100(1-γ) percentage point of the distribution. This estimate, because of the assumptions behind its derivation, requires some careful interpretation relative to measurements made in a given location or over a zone.

TABLE D-1. Normal tolerance factors for upper tolerance limit.

N	g = 0.50			g = 0.90			g = 0.95		
	b = 0.90	b = 0.95	b = 0.99	b = 0.90	b = 0.95	b = 0.99	b = 0.90	b = 0.95	b = 0.99
3	1.50	1.94	2.76	4.26	5.31	7.34	6.16	7.66	10.55
4	1.42	1.83	2.60	3.19	3.96	5.44	4.16	5.14	7.04
5	1.38	1.78	2.53	2.74	3.40	4.67	3.41	4.20	5.74
6	1.36	1.75	2.48	2.49	3.09	4.24	3.01	3.71	5.06
7	1.35	1.73	2.46	2.33	2.89	3.97	2.76	3.40	4.64
8	1.34	1.72	2.44	2.22	2.76	3.78	2.58	3.19	4.35
9	1.33	1.71	2.42	2.13	2.65	3.64	2.45	3.03	4.14
10	1.32	1.70	2.41	2.06	2.57	3.53	1.36	2.91	3.98
12	1.32	1.69	2.40	1.97	2.45	3.37	2.21	2.74	3.75
14	1.31	1.68	2.39	1.90	2.36	3.26	2.11	2.61	3.58
16	1.31	1.68	2.38	1.84	2.30	3.17	2.03	2.52	3.46
18	1.30	1.67	2.37	1.80	2.25	3.11	1.97	2.45	3.37
20	1.30	1.67	2.37	1.76	2.21	3.05	1.93	2.40	3.30
25	1.30	1.67	2.36	1.70	2.13	2.95	1.84	2.29	3.16
30	1.29	1.66	2.35	1.66	2.08	2.88	1.78	2.22	3.06
35	1.29	1.66	2.35	1.62	2.04	2.83	1.73	2.17	2.99
40	1.29	1.66	2.35	1.60	2.01	2.79	1.70	2.13	2.94
50	1.29	1.65	2.34	1.56	1.96	2.74	1.65	2.06	2.86
¥	1.28	1.64	2.33	1.28	1.64	2.33	1.28	1.64	2.33

2.4 Nonparametric upper limit statistical estimate assumptions.

If there is some reason to believe that the data after it has been logarithm transformed will not be sufficiently normally distributed to apply the parametric limits defined above, then consideration must be given to nonparametric bounds i.e., bounds that are not dependent upon assumptions concerning the distribution of estimate values. In this case, there is no need to transform the data estimates. All of the assumptions concerning the selection of estimates are applicable for nonparametric estimates. With additional manipulation, lower limits may be computed using the information in Paragraphs 2.3.1., 2.3.2., and 2.3.3.

2.4.1 ENV - Upper limit.

The maximum envelope limit is determined by selecting the maximum estimate value in the data set.

$$ENV(N) = \max\{X_1, X_2, \ldots\ldots X_N\}$$

The main disadvantage of this estimate is that the distributional properties of this estimate set are neglected so that no probability of exceedance of this value is specified. In the case of outliers in the estimate set, ENV (N) may be far too conservative. ENV (N) is also sensitive to the bandwidth of the estimates.

2.4.2 DFL - Upper distribution-free tolerance limit.

The distribution-free tolerance limit that utilizes the original untransformed sample values is defined to be the upper limit for which the fraction β of all sample values will be less than the maximum predicted or measured value with a confidence coefficient of γ. This is based on order statistic considerations.

$$\mathrm{DFL}(N, \beta, \gamma) = x_{max};\ \gamma = 1 - \beta^N$$

where x_{max} is the maximum value of the set of data; β is the fractional proportion below x_{max}, and γ is the confidence coefficient. Given N, β and γ are not independently selectable. That is:

a. Given N and assuming a value of β, 0 ≤ B ≤ 1, the confidence coefficient can be determined,

b. Given N and γ, the proportion β can be determined,

c. Given β and γ, the number of samples can be determined such that the proportion and confidence can be satisfied (for statistical experiment design).

DFL(N, β, γ) may not be meaningful for small samples of data N ≤ 13 and comparatively large β> 0.95. DFL(N, β, γ) is sensitive to the estimate bandwidth.

2.4.3 ETL - Upper empirical tolerance limit.

The empirical tolerance limit uses the original untransformed sample values and assumes the predicted or measured estimate set is composed of N measurement point over M frequency resolution bandwidths for a total of NM estimate values. That is :

$$\{x_{11}, x_{12}, ..., x_{1M}, x_{21}, x_{22}, ..., x_{2M}, x_{N1}, x_{N2}, ..., x_{NM}\}$$

where m_j is the average at the j^{th} frequency bandwidth over all N measurement points.

$$m_j = \frac{1}{N}\sum_{i=1}^{N} x_{i_j} \quad j = 1, 2, ..., M$$

m_j is used to construct an estimate set normalized over individual frequency resolution bandwidth. That is:

$$\{u_{11}, u_{12}, ..., u_{1M}, u_{21}, u_{22}, ..., u_{2M}, u_{N1}, u_{N2}, ..., u_{NM}\}$$

$$\text{where}: u_{ij} = \frac{x_{i_j}}{m_j} \quad i = 1, 2, ..., N;\ j = 1, 2, ..., M$$

The normalized estimate set {u} is ordered from smallest to largest and

$u_\beta = u_{(k)}$ where $u_{(k)}$ is the k^{th} ordered element of set {u} for $0 < \beta = \frac{k}{MN} \leq 1$ is defined.

For each frequency or frequency band, then

$$\mathrm{ETL}(\beta) = \mu_\beta m_j = x_{\beta_j} \qquad j = 1, 2, ..., M$$

Using m_j implies that the value of ETL(β) at j exceeds β% of the values with 50% confidence. If a value other than m_j is selected, the confidence level may increase. It is important that the set of estimates be homogeneous to use this limit, i.e., they have about the same spread in all frequency bands. In general, the number of measurement points, N, should be greater than 10 to apply this limit.

3 RECOMMENDED PROCEDURES

3.1 Recommended statistical procedures for upper limit estimates.

Reference g provides a discussion of the advantages and disadvantages of estimate upper limits. The guidelines in this reference, will be recommended here. In all cases, the data should be carefully plotted with a clear indication of the method of establishing the upper limit and the assumptions behind the method utilized.

a. When N is sufficiently large i.e., N > 6 establish the upper limit by using the expression for the DFL for a selected $\beta \geq 0.90$ such that $\gamma \geq 0.50$.

b. When N is not sufficiently large to meet the criterion in (1), then establish the upper limit by using the expression for the NTL …Select β and $\gamma \geq 0.50$. Variation in β will determine the degree of conservativeness of the upper limit.

c. For N > 10 and a confidence coefficient of 0.50 is acceptable then the upper limit established on the basis of ETL may be substituted for the upper limit established by DFL or NTL. It is important when using ETL to examine and confirm the homogeneity of the estimates over the frequency band.

3.2 Uncertainty factors

Uncertainty factors may be added to the resulting envelopes if confidence in the data is low or the data set is small. Factors on the order of 3 dB to 6 dB may be added. Reference g recommends a 5.8 dB uncertainty factor based on flight-to-flight and point-to-point uncertainties be added to captive carry flight measured data to determine a maximum expected environment using a normal tolerance limit. It is important that all uncertainties be clearly defined and that uncertainties are not superimposed upon estimates that already account for uncertainties.

ANNEX E

REFERENCE/RELATED DOCUMENTS

a. Harris, C., and C. E. Crede, eds. Shock and Vibration Handbook, 2nd Edition, NY, McGraw-Hill, 1976.

b. Gaberson, H. A. and R. H. Chalmers. Model Velocity as a Criterion of Shock Severity, Shock and Vibration Bulletin 40, Pt. 2, (1969) 31-49.

c. ANSI/ASTM D3332-77, Standard Methods for Fragility of Products Using Machines. 1977.

d. Conover, W.J., practical Nonparametric Statistics. New York; Wiley, 1971, Chapter 3.

e. Piersol, A.G., Analysis of Harpoon Missile Structural Response to Aircraft Launches, Landings and Captive Flight and Gunfire. Naval Weapons Center Report #NWC TP 58890. January 1977.

f. Handbook for Dynamic Data Acquisition and Analysis, IES-RP-DTE012.1, Institute of Environmental Sciences, Mount Prospect, IL.

g. Piersol, Allan G., Detemination of Maximum Structural Responses From Predictions or Measurements at Selected Points, Proceedings of the 65th Shock and Vibration Symposium, Volume I, SAVIAC, 1994.

h. Bendat, J. S., and A. G. Piersol, Random Data : Analysis and Measurement Procedures, John Wiley & Sons Inc., New York 1986

i. Schock, R. W. and W. E. Paulson, TRANSPORTATION A Survey of Shock and Vibration environments in the Four Major Modes of Transportation, Shock and Vibration Bulletin #35, Part 5, February 1966.

j. Ostrem, F. E., TRANSPORTATION AND PACKAGING A Survey of the Transportation Shock and Vibration Input to Cargo, Shock and Vibration Bulletin #42, Part 1, January 1972.

METHOD 404

CONSTANT ACCELERATION

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ANNEX A

METHOD 404

CONSTANT ACCELERATION

1. SCOPE

1.1 Purpose of the Test

The purpose of this test method is to replicate the acceleration environment incurred by systems, subsystems and units, (hereafter called materiel) during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified acceleration environment without unacceptable degradation of its functional and/or structural performance. It is applicable to materiel that is installed in aircraft, helicopter, air carried stores, surface launched missiles and missiles in free flight.

1.3 Limitation

This test method takes no account of the rate of change of acceleration.

2. GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to an acceleration environment.

(1) Deflections that interfere with materiel operation

(2) Permanent deformations and fractures that disable or destroy the materiel.

(3) Breakage of fasteners involving safety.

(4) Short and open circuits.

(5) Variations in inductance and capacitance values.

(6) Malfunctions of relays.

(7) Jamming or bending of mechanisms or servo controls.

(8) Joint seal leaks.

(9) Variation in pressure and flow regulation.

(10) Cavitation of pumps.

(11) Modification of the dynamics characteristics of dampers and isolators.

2.2 Use of Measured Data

Where practicable, field data should be used to develop test levels. It is particularly important to use field data where a precise simulation is the goal. Sufficient field data should be obtained to describe adequately the conditions being evaluated and experienced by the materiel.

2.3 Sequence

The acceleration can be potentially destructive. The Test Instructions should determine its place in the test sequence.

2.4 Choice of Test Procedure

There is only one procedure, but either a centrifuge or a trolley (or sled) may be used. These two test facilities do not necessarily give the same effects. It is for the Responsible Authority to choose the appropriate test facility according to the test items and effects to be simulated.

2.4.1 Centrifuge

The centrifuge generates acceleration loads by rotation about a fixed axis. The direction of acceleration is always radially towards the centre of rotation of the centrifuge, whereas the direction of the load induced by acceleration is always radially away from the centre of rotation. When mounted directly on the test arm, the test item experiences both rotational and translational motion. The direction of the acceleration and the load induced is constant with respect to the test item for a given rotational speed, but the test item rotates 360 degrees for each revolution of the arm.

Certain centrifuges have counter-rotary fixtures mounted on the test arm to correct for rotation of the test item. With this arrangement, the test item maintains a fixed direction with respect to space, but the direction of the acceleration and the induced load rotates 360 degrees around the specimen for each revolution of the arm.

2.4.2 Trolley (sled)

A trolley (sled) arrangement on a track generates linear acceleration in the direction of the sled motion. The test item mounted on the sled is uniformly subjected to the same acceleration level as the sled experiences. The acceleration test level and the time duration at the test level is dependent upon the length of the track, and the sled propulsion system.

This arrangement can produce a significant vibration environment. This vibration may be more severe that the normal service use environment. Careful attention to the attachment design may be needed to isolate the test item from this vibration environment. Telemetry and/or ruggedized instrumentation is required to measure the performance of the test item during the test.

2.5 Controls

2.5.1 Centrifuge

Where necessary, during test, the acceleration shall be checked using suitable sensors. Variations of acceleration shall be controlled within the tolerance requirements of 5.1.1.

The speed rise and descent times should be such that the transverse accelerations are lower than the accelerations specified along the test axis.

2.5.2 Trolley

Where necessary, during the test, the acceleration shall be checked using suitable sensors. Variation of acceleration shall be controlled within the tolerance requirement of 5.1.2.

3. SEVERITIES

3.1 General

When practicable, test levels and durations will be established using projected service use profiles and other relevant available data. When data are not available, initial test severities are to be found in annex A. These severities should be used in conjunction with the appropriate information given in AECTP 200. These severities should be considered as initial values until measured data is obtained. Where necessary, these severities can be supplemented at a later stage by data acquired directly from an environmental measurement programme.

3.2 Supporting Assessment

It should be noted that the test selected may not necessarily be an adequate simulation of the complete environment and consequently, a supporting assessment may be necessary to complement the test results.

3.3 Test Levels

Generally, the test includes two severities :

- Severity 1 : Performance at limit acceleration - Materiel in operation.

  The purpose is to check the correct operation of materiel while it is subjected to the limit accelerations to be encountered in service and to check there is no residual deformation.

  (Limit acceleration is the maximum acceleration which the structure of the materiel should withstand without residual deformation.)

- Severity 2 : Performance in extreme acceleration - Materiel not necessarily in operation.

  The purpose is to check the resistance of materiel to extreme acceleration.

  (Extreme acceleration is the maximum acceleration which the structure of the materiel should withstand without breaking but may have residual deformation. It is the limit acceleration x 1.5.)

4. INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- The location of the control accelerometer
- The definition of the test item
- The orthogonal reference associated with the test item and its origin.
- The pre-conditioning time.
- The operation or non operation of the test item during the test
- The operation checks to be scheduled : initial, during the test, and final ; in particular, for the initial and final checks, specify whether they are to be made with the test item installed on the test apparatus.
- The necessary reference dimensional checks, initial and final.
- The definition of the test severity.

4.2 If Required

- The special features in assembling the test item.

- The effect of gravity and consequent precautions.
- Details relating to radial acceleration gradient.
- Details necessary concerning the speed rise and descent times.

5. TEST CONDITIONS

5.1 Tolerances

5.1.1 Centrifuge

The acceleration obtained should be the acceleration required within ±10 %, at all points of the test item, by setting the rotation speed and distance r. (The acceleration due to gravity is not taken into account).

When the size of the materiel is large in relation to the length of the arm, the test specification may require that only certain sensitive points should be subjected to the acceleration required ± 10 %.

5.1.2 Trolley

The acceleration obtained should be the acceleration required within ±10 % at all points of the test item.

5.2 Installation Conditions of Test Item

The test item should be mounted on the test facility as installed in service.

NOTE : For reasons of safety, take care to avoid the test item being ejected from the machine if the fixing devices break, but any safety device used should not induce any additional stress during the test. A stress calculation should be made on the test set up before the test.

When using a centrifuge, the wires and pipes between the slip ring and the test item should be rigidly fixed on the arm of the centrifuge.

5.2.1 Centrifuge

The orientation of the test item on the centrifuge shall be as follows :

1 Forward acceleration: front side of the test item facing the centre of the centrifuge

2 Backward acceleration: 180° from the position above.

3 Upward acceleration: upper side of the test item facing the centre of the centrifuge.

4 Downward acceleration: 180° from the position above.

5 Acceleration to the left: left hand side of the test item facing the centre of the centrifuge.

6 Acceleration to the right: right hand side of the test item facing the centre of the centrifuge.

NOTE : The terms, front side, upper side, left and right hand side designate the sides of the test item referenced in relation to the orthogonal axes pertaining to the carrier.

5.2.2 Trolley

The orientation of the test item on the trolley shall be as follows:

1 Backward acceleration: front side of test item facing the beginning of the track.

2 Forward acceleration: 180° from the position above.

3 Upward acceleration: upper side of the test item facing the end of the track.

4 Downward acceleration: 180° to the position above.

5 Acceleration to the left: left side of the test item facing the end of the track.

6 Acceleration to the right : right side of the test item facing the end of the track.

5.3 Sub system testing

The sub systems of the materiel may be subjected to different severities. In this case, the Test Instruction should stipulate the severity specific to each sub system.

5.4 Effects of gravity and load factor

Where the performance of the materiel is likely to be affected by the direction of gravity or the load factor (mechanisms, isolators, etc.) these must be taken into account by compensation or by suitable simulation.

5.5 Test preparation

5.5.1 Pre-conditioning

Unless otherwise specified, the test item should be stabilised to its initial conditions as stipulated in the Test Instruction.

5.5.2 Initial checks, during the test and final

These checks include the controls and examinations stipulated in the Test Instruction. The final checks are made after the materiel has been returned to rest in normal controlled atmospheric conditions and thermal stability is obtained.

5.6 Procedure

Step 1. Install the test item so that the direction of the acceleration is parallel to the axis defined by the Test Instruction.

Step 2. Make the initial checks.

Step 3. Apply the required acceleration for the specified time. The test item is to be operated when required in the Test Instruction.

Step 4. Make the final checks

Step 5. Unless otherwise specified, apply the constant acceleration in each of the other five remaining directions. The order of application is not mandatory, but it is advisable to begin with the lowest acceleration level.

Step 6. In all cases, record the information required by the Test Instruction.

6. FAILURE CRITERIA

The test item performances shall meet all appropriate specification requirements during and following the test.

ANNEX A

GUIDANCE FOR INITIAL TEST SEVERITIES

When data are not available for the definition of the service environment, the following values may be used for initial design and testing.

Carrier	Fore	Aft	Up	Down	Left	Right
Light Aircraft	3	5	5	3	5	5
Propeller Aircraft	1	1.5	10	8.5	5	5
Jet Transport	1.5	2	8	5	3	3
Combat Aircraft	10	15	15	15	15	15
External Stores						
wing	15	20	20	20	20	20
fuselage	10	15	15	15	15	15
Helicopter	2	2	7	3	4	4
External Stores	2	2	7	3	4	4
Missiles (free flight)						
Anti aircraft	30	10	50	50	50	50
Anti missile	50	10	100	100	100	100
Surface target	10	10	20	20	20	20

Duration : unless otherwise specified, the duration shall be sufficient to conduct checks as detailed in the test specification.

TABLE A1

LEVELS IN "gn" FOR SEVERITY 1 (LIMIT ACCELERATION)

Ref : multiple sources

METHOD 405

GUNFIRE

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ANNEX A

DIRECT REPRODUCTION OF MEASURED MATERIEL RESPONSE DATA

ANNEX B

STATISTICALLY GENERATED REPETITIVE PULSE - MEAN (DETERMINISTIC) PLUS RESIDUAL (STOCHASTIC) PULSE

ANNEX C

REPETITIVE PULSE SHOCK RESPONSE SPECTRUM (SRS)

ANNEX D

HIGH LEVEL RANDOM VIBRATION/SINE-ON-RANDOM VIBRATION NARROW RANDOM ON RANDOM VIBRATION (GUIDANCE FOR TEST SEVERITIES)

METHOD 405

GUNFIRE

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the gunfire environment response incurred by systems, subsystems, components and units, (hereafter called materiel) during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the repetitive gunfire environment without unacceptable degradation of its functional and/or structural performance.

1.3 Limitations

It may not be possible to simulate some actual operational service gunfire environment response because of fixture limitations or physical constraints that may prevent the satisfactory application of the gunfire excitation to the test item. This test method is not intended to simulate temperature or blast pressure effects due to gunfire.

2. GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel are exposed to a gunfire environment.

1). Wire chafing

2). Loosening of fasteners

3). Intermittent electrical contacts

4). Touching and shorting of electrical parts

5). Seal deformation

6). Structural deformation

7). Structural and component fatigue

8). Optical misalignment

9). Cracking and rupturing

10). Loosening of particles or parts that may become lodged in circuits or mechanisms.

11). Excessive electrical noise.

2.2 Use of Measured Data

Measured data from field gunfiring should be used to develop test levels for Procedures 1, 2, 3, and 4. It is particularly important to use field-measured data where a precise response simulation is the goal.

Sufficient field measured data should be obtained to adequately describe the conditions being evaluated and experienced by the materiel. The quality of field measured gunfire data should be verified in accordance with reference c prior to developing test levels.

2.3 Sequence

The response to gunfire may effect materiel performance when materiel is tested under other environmental conditions, such as vibration, shock, temperature, humidity, pressure, electromagnetics, etc. It is essential that materiel which is likely to be sensitive to a combination of environments be tested to the relevant combinations simultaneously.

Where it is considered that a combined test is not essential or impractical to configure, and where it is required to evaluate the effects of gunfire together with other environments, a single test item should be exposed to all relevant environmental conditions in turn.

The order of application of tests should be considered and made compatible with the Service Life Environmental Profiles. If any doubts remain as to the order of testing, then any gunfire testing should be undertaken immediately after completing vibration testing.

2.4 Rationale for Procedures and Parameters

Response to gunfire is characterized by a high level non-stationary (time-varying) vibration or repetitive shock that in general is superimposed upon an ambient vibration environment. Gunfire response has principal frequency components at the firing rate of the gun and its harmonics. Ambient vibration is defined by comparatively low level energy distributed fairly uniformly at frequencies other than the principal frequency components throughout the band of measurement. Response of particular materiel to gunfire is dependent upon the dynamic characteristics of the materiel itself. The gunfire environment is considered to be time-varying because it usually has a time-varying root-mean-square (rms) level that is substantially above the ambient or aircraft induced environmental vibration level for a comparatively short period of time. Because of the nature of the measured response data (for cases in which the environment is considered a series of well defined pulses at a particular repetition rate), the analysis is usually not easily interpreted in terms of either stationary measures of the environment such as auto-spectral density estimates, or transient measures of the environment in terms of shock response spectra. If the analysis of the measured data concludes that the result of gunfire is only a slight increase in the ambient vibration level with no readily distinguishable pulse time characteristics, stationary random vibration analysis techniques may be used to specify the test, or procedure 4 may be used.

2.5 Choice of Test Procedures

The procedures are given in order of preference based on the ability of the test facility to replicate the gunfire environment. Improper test procedure selection may result in a severe under test or over test.

Nonstationary (time-varying) Vibration

- Procedure 1: Direct Reproduction of Measured Materiel Response Data
- Procedure 2: Statistically Generated Repetitive Pulse - Mean (deterministic) plus Residual (stochastic) Pulse
- Procedure 3: Repetitive Pulse Shock Response Spectrum (SRS)

Stationary Vibration

- Procedure 4: High Level Random Vibration/Sine-on-Random Vibration/Narrowband Random-on-Random Vibration (Guidance for Initial Test Severities)

These procedures can be expected to cover the entire range of testing related to materiel exposed to gunfire environment. For example, in cases of severe materiel response to gunfire environment with highly sensitive components, only Procedures 1 and 2 are appropriate. The use of these procedures requires that the materiel response data has been measured at hard points on the materiel, and the materiel can be so fixtured that the test input environment configuration is very similar to the measured input environment configuration.

Procedure 1 is recommended as the most suitable test procedure because it provides the most accurate replication of the dynamic response of the material.

Procedure 2 is recommended as the second most suitable procedure as it provides good accuracy of replicating material dynamic response in addition to providing flexibility with regard to pulse randomization and gunfire burst length.

Procedure 3 is inferior to Procedures 1 and 2 because materiel time domain gunfire response characteristics can not be simulated as precisely using Shock Response Spectra techniques (i.e., complex transient waveform generation), but it can be used where test facility limitations preclude the use of Procedures 1 and 2.

Procedure 4 is applicable in cases in which the materiel is distant from the gunfire input environment, and measured data at appropriate hard points of the materiel indicate a random vibration gunfire environment only slightly above the most severe measured random vibration level. Procedure 4 is also appropriate for aircraft gunfire in the absence of measured data where Annex D provides guidelines for a predicted aircraft gunfire environment. The procedure provides guidance for initial test severities where no measured data is available.

It is assumed in applying these procedures that the dynamics of the material are well known, in particular, the resonance's of the material and the relationship of these resonance's to the gun firing rate and its harmonics. It is recommended that this materiel dynamic response information be used in selecting a procedure and designing a test using this procedure.

2.6 Types of Gunfire Materiel Response Simulation

A brief description of each type of gunfire simulation procedure is given in the following paragraphs.

Procedure 1 Direct Reproduction of Measured Materiel Response Data

Service-use gunfire materiel response is duplicated to achieve a near exact simulated reproduction of the measured gunfire response acceleration time history. Guidelines are provided in Annex A.

Procedure 2 Statistically Generated Repetitive Pulse – Mean (deterministic) plus Residual (stochastic) Pulse

Characteristics of the service-use gunfire materiel response are statistically modeled (usually by creating a "pulse ensemble" and obtaining a time varying mean "pulse" and its associated residuals via nonstationary data processing), and the statistical model of the gunfire response is simulated to achieve a very good reproduction of the measured gunfire acceleration time history. Guidelines are provided in Annex B.

Procedure 3 Repetitive Pulse Shock Response Spectrum (SRS)

The measured gunfire acceleration time history is broken into individual pulses for analysis. Maximax shock response spectra are computed over the individual pulses to characterize the gunfire environment with a unique SRS. An acceleration time history is composed that has a duration equivalent to an individual measured gunfire pulse and that exhibits the characteristic gunfire SRS. The characteristic SRS gunfire pulse is repeated at the gun-firing rate. Guidelines are provided in Annex C.

Procedure 4 High Level Random Vibration/Sine-on-Random Vibration/Narrowband Random-on-Random Vibration (Guidance for Initial Test Severities)

If no pulse form is indicated by the measured service-use gunfire response data (in general the firing rate of the gun cannot be determined from an examination of the field measured response time history), or the materiel is distant from the gun and only high level random vibration is exhibited, guidelines provided in Method 401 shall be used. In the absence of measured response data, Annex D provides guidance for initial test severities.

2.7 Control

2.7.1 Control strategy

The dynamic excitation is controlled to within specified bounds by sampling the dynamic response motions of the test item at specific locations. These locations may be at or in close proximity to the materiel fixing points (controlled input tests) or at defined points on the materiel (controlled response tests). The dynamic response motions may be sampled at a single point (single point control) or at several locations (multi-point control).

The control strategy depends on:

- the results of preliminary vibration/resonance search surveys carried out on materiel and fixtures,
- meeting the test specifications within the tolerances of 5.1,
- the capability of the test facility.

2.7.2 Control options

2.7.2.1 Single point control

Single point control is required for Procedures 1 through 3, and optional for Procedure 4. A single response point shall be selected to represent the materiel hard point from which the field measured response data were obtained or upon which predictions were based.

2.7.2.2 Multiple point control

In cases where the materiel is distant from the gunfire input environment, and the measured data at appropriate hard points indicate no more than a random vibration environment slightly above ambient conditions, multiple point control may be desirable for Procedure 4. Multiple point control will be based on the control strategy and on the average of the ASD's of the control points selected.

2.7.3 Control methods

2.7.3.1 Open Loop Vibration control

Application of the techniques for Procedures 1 through 3 will generally involve a computer with digital-to-analog interface and analog-to-digital interface with the analog output going directly to drive the shaker. Signal processing will be performed off-line or open loop where the resulting shaker drive signal will be stored as a digital signal. During testing, feedback response will be monitored only for abort conditions.

2.7.3.2 Close Loop Vibration Control

For Procedure 4 closed loop vibration control is to be used. Because the loop time depends on the number of degrees of freedom and on the analysis and overall bandwidths, it is important to select these parameters so that test tolerances and control accuracy can be respected. During testing, feedback response will be monitored and used for both control conditions and abort conditions.

3. SEVERITIES

3.1 General

The test severities will be established using available data or data acquired directly from an environmental data gathering program. When these data are not available, initial test severities and guidance may be found in Annex D. Test guidance is provided in Annexes A through C for cases in which data has been collected and a precise simulation is desired. It should be noted that the test selected might not necessarily be an adequate simulation of the complete environment; thus, a supporting assessment may be necessary to complement the test results.

4. INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTIONS

4.1 Compulsory

- the identification of the materiel
- the definition of the materiel
- the orientation of the materiel in relation to test axes
- operating or nonoperating condition of the materiel during test
- the operational checks: initial, during the test, and final
- for the initial and final checks, specify whether they are performed with the materiel installed on the test facility
- the details required to perform the test
- the preconditioning time
- the use of isolator mounts and their characteristics
- the definition of the test severity
- the failure criteria
- the control strategy
- any other environmental conditions at which testing is to be carried out if other than standard laboratory conditions.
- the specific features of the test assembly (shaker, fixture, interface connections, etc.)

4.2 If required

- the effect of gravity and the consequent precautions
- tolerances, if different from paragraph 5.1.

5. TEST CONDITIONS

5.1 Tolerances

Unless otherwise specified in the Test Instruction, the tolerances applied to the single gun-firing rate (swept or unswept) are ± 2.5%. The complete test parameter control systems (checking, servoing, recording, etc.) should not produce uncertainties exceeding one third of the tolerance values specified in 5.1.1 through 5.1.4.

5.1.1 Procedure 1

a) Time domain: Ensure the duration of one pulse is within ±2.5% duration of the measured gunfire rate.

b) Amplitude domain: Ensure materiel time history response peaks are within ±10% of the measured gunfire time history peaks.

c) Frequency domain: Compute an average energy spectral density (ESD) estimate over the ensemble created from the materiel time history response that is within ±3 dB of the average ESD estimate computed over the ensemble created from the measured gunfire response time history. In cases in which an ensemble from the data cannot be created, compute an autospectral density (ASD) estimate of the time history records for comparison provided the data is appropriately windowed to reduce spectral leakage. The tolerances for the ASD analysis are ±3 dB.

5.1.2 Procedure 2

a) Time domain: Ensure the duration of one pulse is within ±2.5% duration of the measured gunfire rate.

b) Amplitude domain: Ensure materiel time history response peaks are within ±10% of the measured gunfire time history peaks.

c) Frequency domain: Compute an average energy spectral density (ESD) estimate over the ensemble created from the materiel time history response that is within ±3dB of the average ESD computed over the ensemble created from the measured gunfire time history response.

5.1.3 Procedure 3

a) Time domain: Ensure the duration of one pulse is within ±5% duration of the measured gunfiring rate.

b) Amplitude domain: Ensure materiel time history response peaks are within ±10% of the measured gunfire time history response peaks.

c) Frequency domain: Ensure the maximax shock response spectrum (SRS) computed over the materiel time history response from one simulated gunfire pulse is within +3dB and –1dB from the mean SRS computed over the ensemble of field measured materiel response data. Use an SRS analysis with at least 1/6 octave frequency spacing.

5.1.4 Procedure 4

a) Time domain. Ensure the root-mean-square (RMS) value of the amplitude measured at the control point in the test axis is within ±5% of the preset RMS value. Likewise, ensure the maximum variation of the RMS value at the fixing points in the test axis is ±10% of the preset RMS value.

b) Amplitude domain. Ensure the amplitude distribution of the instantaneous values of the random vibration at the control point is nominally Gaussian. Use an amplitude distribution that contains all occurrences up to 2.7 standard deviations. Keep occurrences greater than 3.5 standard deviations to a minimum.

c) Frequency domain. Ensure an autospectral density analysis (ASD) of the materiel time history response is within ±3dB of an ASD computed over the field measured gunfire data or the predicted gunfire environment. Allow exceedances up to ±6 dB above 500 Hz, but limit the accumulation of all local exceedances to 5% of the overall test frequency range. Use a maximum analysis filter bandwidth of 5 Hz and attempt to have the number of independent statistical degrees of freedom (DOF) for control greater than 100. Ensure the ASD measured along the two transverse orthogonal axes, using the same number of DOF as that used for the control, is less than 25% of the specified ASD of the control point over 90% of the overall bandwidth.

5.2 Installation Conditions of Test Item

Test items can vary from individual materiel items to structural assemblies containing several items of materiel of different types. The test procedures should takeinto account the following:

- fixturing should simulate actual service use mounting attachments (including vibration isolators, and fastener torque's, if appropriate.)
- all the connections (cables, pipes, etc.) should be installed in such a way that they impose stresses and strains on the test materiel similar to those encountered in service use.
- the possibility of exciting the test materiel simultaneously along several axes using more than one vibration exciter.
- suspension of test materiel at low frequency to avoid complex test fixture resonance's and utilization of a force entry frame.
- The direction of gravity or the load factor may be taken into account by compensation or by suitable simulation. For high g aircraft maneuvers the effects of gravity may be substantial and require separate acceleration testing of the materiel.

5.2.1 Test set-up

5.2.1.1 General

Unless otherwise specified in the individual Test Instruction, the test materiel shall be attached to the vibration exciter by means of a rigid fixture capable of transmitting the vibration conditions specified. The fixture should input vibration to racks, panels, and/or vibration isolators to simulate as accurately as possible the vibration transmitted to the materiel in service use. When required, materiel protected from vibration by these means should also pass the appropriate test requirements with the test materiel hard-mounted to the fixture.

5.2.1.2 Stores

When the materiel is a store, use the following guidelines:

Where practical, testing shall be accomplished in three mutually perpendicular axes with the mounting lugs in the normal carriage position. Suspend the store from a structural frame by means of its normal mounting lugs, hooks, and sway braces, which simulate the operational mounting apparatus. The test set-up shall be such that the rigid body modes (translation and rotation) or vibration for the store/frame/suspension system are between 5 and 20 Hz. Vibration shall be applied to the store by means of a rod or other suitable mounting device running from a vibration shaker to a relatively hard, structurally supported point on the surface of the store. Alternatively, the store may be hard-mounted directly to the shaker using its normal mounting lugs and a suitable fixture. The stiffness of the mounting fixture shall be such that its induced resonant frequencies are as high as possible and do not interfere with the store response. For all methods, launcher rails shall be used as part of the test set-up, where applicable. Because of the nature of the response to be simulated, such testing configuration, except for Procedure 4, may be difficult to accomplish for a store.

5.3 Subsystem Testing

When identified in the Test Instruction, subsystems of the materiel may be tested separately. The subsystems can be subjected to different gunfire levels. In this case the Test Instruction should stipulate the gunfire levels specific to each subsystem.

5.4 Test Preparation

5.4.1 Preconditioning

Test materiel should be stabilized to its initial climatic and other conditions as stipulated in the Test Instruction.

5.4.2 Operational checks

All operational checks including all examinations should be undertaken as stipulated in the Test Instruction. The final operational checks should be made after the materiel has been returned to rest under preconditioning conditions and thermal stability has been obtained.

5.5 Procedures

The Test Instruction should stipulate whether the materiel is or is not in operation during test. Because continuous gunfire vibration testing can cause unrealistic damage of the materiel (for example, unrealistic heating of vibration isolators), the excitations should be interrupted by periods of rest, defined by the Test Instruction. For additional details with regard to paragraphs 5.5.1 through 5.5.4, refer to Annexes A, B, C, and D.

5.5.1 Procedure 1 - Direct Reproduction of Measured Materiel Response Data

Step 1. Obtain a digital representation of the field measured response data. In general this will involve the digitalization of a full measured materiel acceleration response for input to the vibration control system. (refer to annex A)

Step 2. Precondition in accordance with paragraph 5.4.1.

Step 3. Choose control strategy and control points and monitoring points in accordance with paragraphs 2.7.1, 2.7.2.1, and 2.7.3.1.

Step 4. Perform operational checks in accordance with paragraph 5.4.2.

Step 5. Mount the test materiel on the vibration exciter in accordance with paragraph 5.2.

Step 6. Determine the time history representation of the vibration exciter drive signal voltage required to provide the desired gunfire acceleration response. (refer to Annex A).

Step 7. Apply the drive signal voltage as an input voltage and measure the test materiel acceleration response at the selected control point (and monitoring points).

Step 8. Verify that the test materiel response is within the allowable tolerances specified in paragraph 5.1 and 5.1.1.

Step 9. Apply gunfire simulation for on and off periods and total test duration in accordance with the Test Instruction. Perform operational and functional checks in accordance with the Test Instruction.

Step 10. Repeat the previous steps along each other axis specified in the Test Instruction.

Step 11. In all cases, record the information required.

5.5.2 Procedure 2 - Statistically Generated Repetitive Pulse – Mean (deterministic) plus Residual (stochastic) Pulse

Step 1. Generate a statistical representation of the field measured data. In general this will involve an off-line procedure designed to generate an ensemble of pulses based on measured data for input to the vibration control system. (refer to Annex B).

Step 2. Precondition in accordance with paragraph 5.4.1.

Step 3. Choose control strategy and control and monitoring points in accordance with paragraphs 2.7.1, 2.7.2.1, and 2.7.3.1.

Step 4. Perform operational checks in accordance with paragraph 5.4.2.

Step 5. Mount the test materiel on the vibration exciter in accordance with paragraph 5.2.

Step 6. Determine the time history representation of the vibration exciter drive signal voltage required to provide the desired gunfire acceleration response. (refer to Annex B).

Step 7. Apply the drive signal voltage as an input voltage and measure the test materiel acceleration response at the selected control point (and monitoring points).

Step 8. Verify that the test materiel response is within the allowable tolerances specified in paragraph 5.1 and 5.1.2.

Step 9. Apply gunfire simulation for on and off periods and total test duration in accordance with the Test Instruction. Perform operational and functional checks in accordance with the Test Instruction.

Step 10. Repeat the previous steps along each other axis specified in the Test Instruction.

Step 11. In all cases, record the information required.

5.5.3 Procedure 3 – Repetitive Pulse Shock Response Spectrum (SRS)

Step 1. Separate the measured field data into individual pulses and compute Shock Response Spectra over the individual pulses using damping factors of 5%, 2%, 1%, and 0.5%

(Q = 10, 25 , 50, and 100).

- Compute the statistical mean Shock Response Spectrum (SRS) for each of the respective damping factors used.
- Compare the mean shock spectra for each of the damping factors to determine the predominant frequencies and to obtain an estimate of the duration or “half cycle content” comprising the individual predominant frequencies. Note: An individual selected pulse (as the result of separation of the measured field data into individual pulses) may be used instead of the mean shock spectrum for each of the damping factors.

- Characterize the SRS time history using the estimate of the duration or “half cycle content” for specification of “wavelet” duration, and choose either the mean SRS or an individual pulse for amplitude characterization. This procedure assumes the complex SRS waveform generation is based upon amplitude modulated sine functions (“wavelets”).
- Refer to Annex C for complete details.

Step 2. Precondition in accordance with paragraph 5.4.1.

Step 3. Choose control strategy and control and monitoring points in accordance with paragraphs 2.7.1, 2.7.2.1, and 2.7.3.1.

Step 4. Perform operational checks in accordance with paragraph 5.4.2.

Step 5. Mount the test materiel on the vibration exciter in accordance with paragraph 5.2.

Step 6. Compensate the exciter drive signal.

Step 7. Input the SRS transient drive signal voltage through the shaker control system at the firing rate of the gun, and measure the test materiel acceleration response at the selected control point (and monitoring points).

Step 8. Verify that the test materiel response is within the allowable tolerances specified in paragraphs 5.1 and 5.1.3.

Step 9. Apply gunfire simulation on and off periods and total test duration in accordance with the Test Instruction. Perform operational and functional checks in accordance with the Test Instruction.

Step 10. Repeat the previous steps along each other axis specified in the Test Instruction.

Step 11. In all cases, record the information required.

5.5.4 Procedure 4 - High Level Random Vibration/Sine-on-Random Vibration/Narrowband Random-on-Random Vibration. (Guidance for Initial Test Severities)

Step 1. -Compute an autospectral density estimate over the measured gunfire materiel response data using an overall analysis bandwidth of 2000 Hz with a maximum 5 Hz analysis bandwidth resolution, or compute a 2000 Hz autospectral density prediction.

-Generate a random vibration test spectrum from the measured data, or from the prediction generate a test spectrum consisting of a broadband random base with four superimposed discrete frequency peaks that occur at the fundamental firing rate of the gun and the first three harmonics of the firing rate.

- Refer to Annex D for complete details.

Step 2. Precondition in accordance with paragraph 5.4.1.

Step 3. Choose control strategy and control and monitoring points in accordance with paragraphs 2.7.1, 2.7.2.1, 2.7.2.2, and 2.7.3.2.

Step 4. Perform operational checks in accordance with paragraph 5.4.2.

Step 5. Mount the test materiel on the vibration exciter in accordance with paragraph 5.2.

Step 6. Input the vibration profile through the appropriate shaker control system support software.

Step 7. Apply the drive signal voltage as input and measure the test materiel acceleration response at the selected control point or points (and monitoring points).

Step 8. Verify that the test item response is within the allowable tolerances specified in paragraphs 5.1 and 5.1.4.

Step 9. Apply gunfire simulation on and off periods and total test duration in accordance with the Test Instruction. Perform operational and functional checks in accordance with the Test Instruction.

Step 10. Repeat the previous steps along each other axis specified in the Test Instruction.

Step 11. In all cases, record the information required.

6. FAILURE CRITERIA

The materiel performances shall meet all appropriate specification requirements during and following the application of gunfire simulation. In general, the operational and structural integrity of the materiel shall be preserved during testing. Any compromise of either operational and/or structural integrity of the materiel shall constitute failure of the materiel in testing.

7. REFERENCES AND RELATED DOCUMENTS

a) Harris, C,. and C.E. Crede, eds. Shock and Vibration Handbook, 2nd edition, NY, McGraw-Hill, 1976

b) Piersol, A.G., Analysis of Harpoon Missile Structural Response to Aircraft Launches, Landings and Captive Flight and Gunfire, Naval Weapons Center Report #NWC TP 58890, January, 1977.

c) Handbook for Dynamic Data Acquisition and Analysis, Design Test and Evaluation Division. Recommended Practice 012.1 IES - PR - DTE - 012.1, Institute of Environmental Sciences, 940 East Northwest Highway, Mount Prospect, Illinois

d) Bendat, J.S. and A.G. Piersol, Random Data : Analysis and Measurement Procedures, John Wiley and Sons Inc, NY, 1986

ANNEX A

DIRECT REPRODUCTION OF MEASURED MATERIEL RESPONSE DATA

1. SCOPE

1.1 Purpose

This Annex provides guidance and a basis for direct reproduction of measured materiel response data in a laboratory test on an electrodynamic shaker (vibration exciter) under waveform control in an open loop mode.

1.2 Application

This technique is useful for the reproduction of single point materiel response that may be characterized as nonstationary or as a transient vibration. Acceleration, is considered the variable of measurement in the discussion to follow although other variables could be used, provided the dynamic range of the measured materiel response is consistent with the dynamic range of the electrodynamic shaker system used as an input device to reproduce the materiel response.

2. DEVELOPMENT

2.1 Basic Consideration for Environment Determination

It is assumed that an in-service environmental measurement test is performed with properly instrumented materiel where the measurements are made at preselected points of the materiel. The measurement points exhibit minimum local resonances, yet the measurement locations will allow the detection of significant overall materiel resonances. The measurement locations may be determined prior to making an in-service test by examination of random vibration data on the materiel using various accelerometer mounting locations and fixturing configurations (the same as those to be used in laboratory testing). In processing, ensure the field measured data is DC coupled (not high pass filtered) and sampled at ten times the highest frequency of interest. Examine the measured data time history traces for any indication of clipping, or any accelerometer performance peculiarities such as zero shifting (that may be the case for any potential high level form of mechanical shock). If there is indication of accelerometer measurement anomalies, examine a potentially corrupted acceleration time history carefully according to the procedures used in qualifying pyrotechnic shock data, e.g., time history integration to examine velocity and displacement characteristics, sample PSD's computed, etc. (for further details see reference a). If there is no indication of accelerometer anomalies, the in-service measured data is AC coupled (high pass filtered at a very low frequency, e.g., 1 Hz) and sampled at ten times the highest frequency of interest (i.e., the anti-alias filter upper cutoff limit which is generally around 2000 Hz), and placed in a digital file for manipulation. An example of gunfire simulation using the Direct Reproduction of Measured Materiel Response Data technique is discussed below. This procedure is performed on a personal computer (PC) with signal processing capability and analog-to-digital and digital-to-analog interfaces.

2.2 Test Configuration

A specially instrumented test item is installed in a laboratory vibration fixture and mounted to the armature of an electrodynamic shaker. The test item employed during the laboratory simulation is the same materiel configuration used to collect the captive-carry gunfire vibration materiel response data during an in-service test. A piezoelectric accelerometer is installed internal to the test item for purposes of acceleration response input control.

2.3 Creating a Digital File of the Gunfire Vibration Response

The first step in this simulation process is to digitize the measured flight data to obtain an amplitude time history (Figure A1). Digital processing of the analog data was performed using a 2,000-Hz, 48dB/octave anti-alias filter and a sample rate of 20,480 samples per second for good time history amplitude resolution. The anti-alias filter should have linear phase characteristics.

2.4 Characterization of Shaker Drive Signal/Test Item Inverse Frequency Response Function

Definition of the inverse frequency response function between the shaker drive signal and the acceleration response of the test item installed on the shaker is achieved by subjecting the test item to a low level of swept sine excitation. The swept sine excitation is generated on the PC using a sample rate of 20,480 samples per second and a block size of 2,048 points for a duration of approximately 0.1 seconds. The swept sine input utilizes a start frequency of 10-Hz and a stop frequency of 2,000-Hz. The swept sine excitation is input through the shaker power amplifier using the digital-to-analog interface of the PC. Figure A-2 presents the swept sine shaker input along with the resulting test item response (Figure A2b). The swept sine shaker input and the test item response were digitized utilizing the PC analog-to-digital interface using a sample rate of 20,480 samples per second and a block size of 2,048 points. The inverse frequency response function, IH (f), is estimated as follows.

$$IH(f) = E_{dd}(f) / E_{dx}(f)$$

where

E_{dd} = the input energy spectral density of the swept sine shaker drive signal d(t)

E_{dx} = the energy spectral density cross spectrum between the acceleration response of the test item x(t), and the swept sine shaker drive signal, d(t)

Figure A-3 presents the modulus and phase of the inverse frequency response function. To reduce the noise in IH(f) three or more IH(f) estimates may be averaged. Under laboratory conditions, usually the signal-to-noise ratio is so high that averaging to reduce noise levels in the estimate is unnecessary (see reference b and c).

2.5 Tapering the Inverse Frequency Response Function

Because the signal processing software computes the inverse frequency response function out to the sampling rate Nyquist frequency, which is far above the frequency range of interest, a tapering function is applied to the inverse frequency response function. The tapering function removes the unwanted frequency content (noise) beyond the frequency band of interest (10 - 2,000-Hz). The modulus is reduced to zero from 2,000-Hz over a bandwidth of approximately 200-Hz; whereas, the phase remains constant beyond 2,000-Hz. The modulus and phase of the tapered inverse frequency response function is presented in Figure A-4. Some experimentation with the tapering configuration may be needed at this point on behalf of the tester to optimize the information preserved in the 10 – 2000 Hz frequency domain.

2.6 Computing the Impulse Response Function

The impulse response function is generated by computing the inverse Fourier transform of the tapered inverse frequency response function and is displayed in Figure A-5.

2.7 Computing the Compensated Shaker Drive Signal

The compensated shaker drive signal is generated by convolution of the impulse response function (Figure A-5) in units of (volts/g) with the measured gunfire materiel response (Figure A-1) in units of (g). This could also be accomplished in the frequency domain by multiplying transforms i.e., IH(f) by the transform of an unwindowed block of time history using either overlap-and-save or overlap-and-add procedures. The compensated shaker drive signal is illustrated in the top portion of Figure A-6

2.8 Reproducing the Gunfire Materiel response

Utilizing the digital-to-analog interface capability of the PC, the compensated shaker drive signal is input through the shaker power amplifier to obtain the desired gunfire materiel response from the test item. The shaker is under waveform control in an open loop mode of operation. For the short duration of the nonstationary record or transient vibration, this is an adequate mode of shaker control. Figure A-6 presents the compensated shaker drive signal along with the resulting materiel response. Figure A-7 is a comparison of the overall in-service measured gunfire materiel response with the laboratory simulated gunfire test item response.

2.9 Conclusion

For single point materiel response measurements on comparatively simple dynamic materiel, the method of direct reproduction of in-service measured materiel response is near "optimal". The main advantage of this technique is that it permits reproduction of materiel responses (nonstationary or transient vibration) that are difficult, if not impossible, to completely specify and synthesize for input to a shaker control system. The main disadvantage of this technique being that there is no obvious way to statistically manipulate the measured materiel response data to insure a conservative test. However, conservativeness could be introduced into the testing by performing the manipulation at a reduced level of shaker power amplifier gain and then testing at the higher gain. The assumption behind this technique is that the test item response resulting from the shaker input is a linear function of the power amplifier gain. This linearity assumption would need to be independently verified before testing.

2.10 Reference/Related Documents

a) Handbook for Dynamic Data Acquisition and Analysis, Design Test and Evaluation Division. Recommended Practice 012.1 IES - PR - DTE - 012.1, Institute of Environmental Sciences,
940 East Northwest Highway, Mount Prospect, Illinois

b) Merritt, R.G. and S. R. Hertz, Aspects of Gunfire, Part 1. Analysis, NWC TM 6648 Part 1, October 1990, Naval Weapons Center, China Lake, CA 93555-6100

c) Merritt, R.G. and S. R. Hertz, Aspects of Gunfire, Part 2. Simulation, NWC TM 6648 Part 2, September 1990, Naval Weapons Center, China Lake, CA 93555-6100

3. RECOMMENDED PROCEDURES

3.1 Recommended Procedures

For single materiel response measurements, on comparatively simple dynamic materiel, use this procedure. This procedure is to be used in cases which laboratory replication of the response environment is absolutely essential to establish materiel operational and structural integrity under gunfire environment.

3.2 Uncertainty Factors

The only significant uncertainty in this procedure results in the degree to which the measured environment differs from the actual in-service environment. It is usually not possible to obtain the measured environment under every conceivable in-service condition.

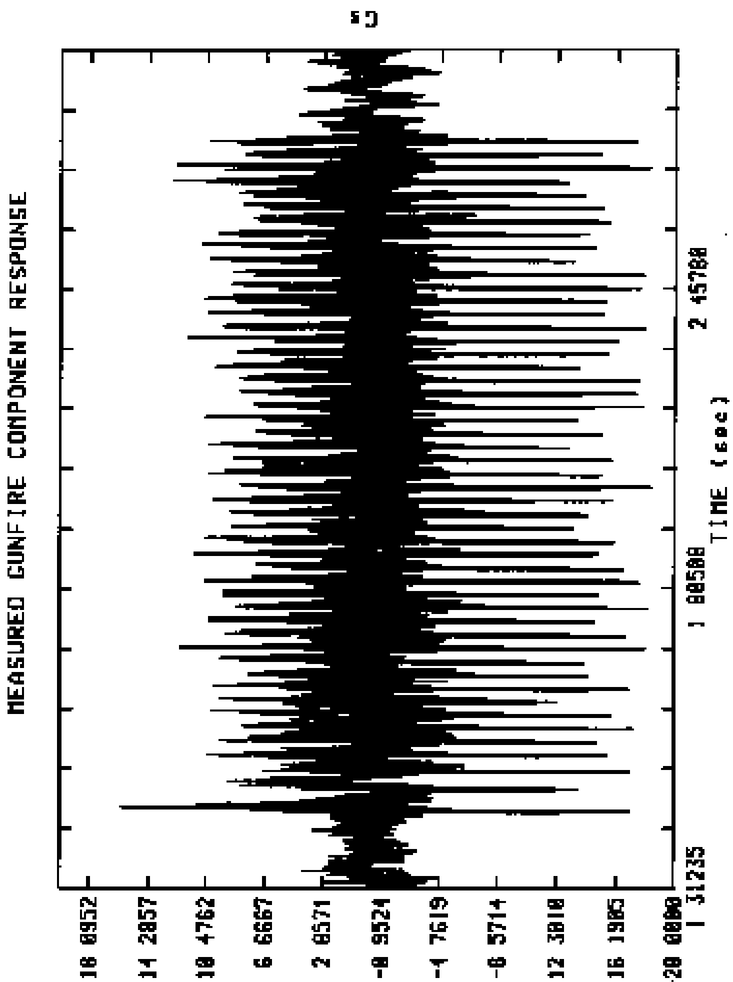
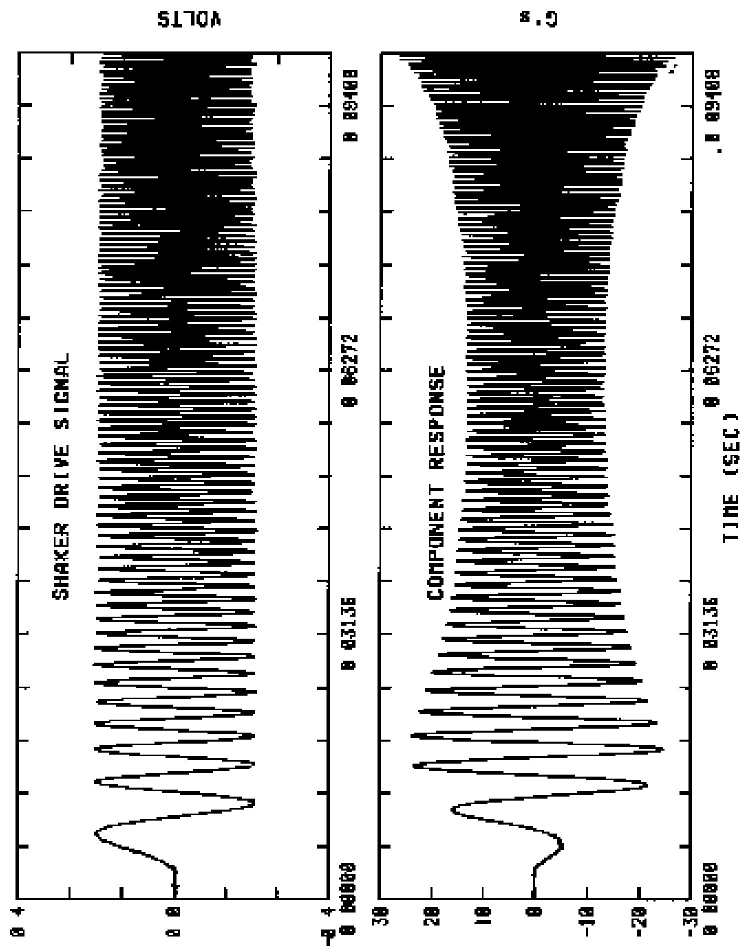
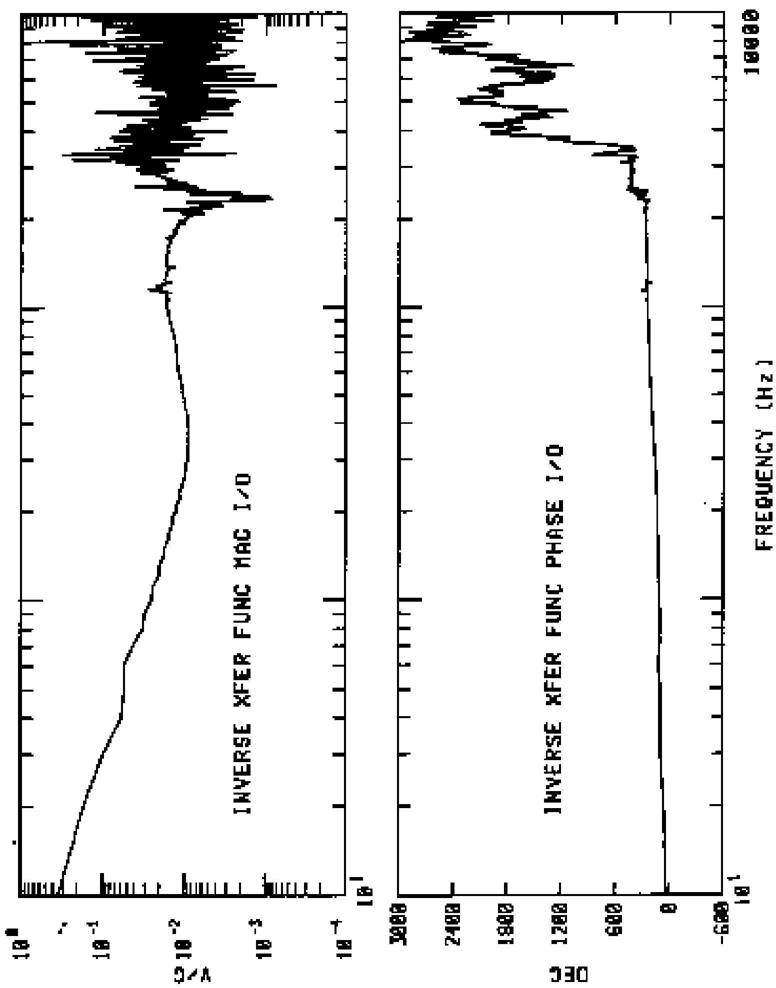


FIGURE A-1. Digital flight data.



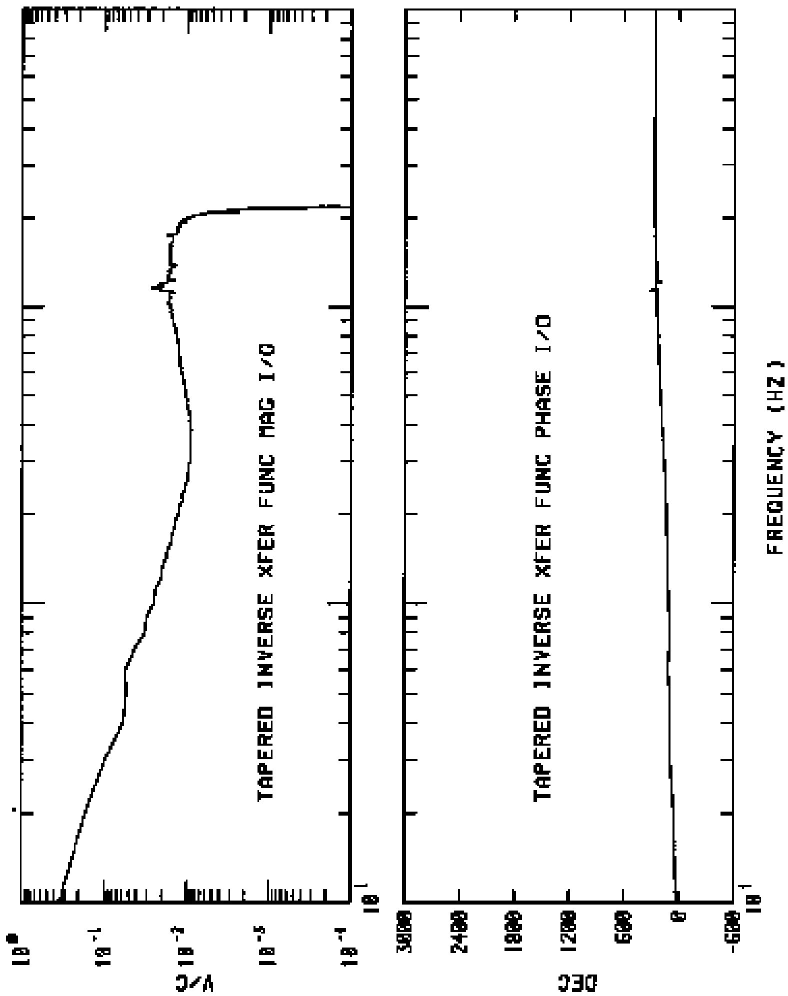
a. Input b. Response

FIGURE A-2. Swept sine shaker input with resulting test item response.



a. Modulus b. Phase

FIGURE A-3. Modulus and phase of inverse frequency response function.



a. Modulus b. Phase

FIGURE A-4. Modulus and phase of tapered inverse frequency response function.

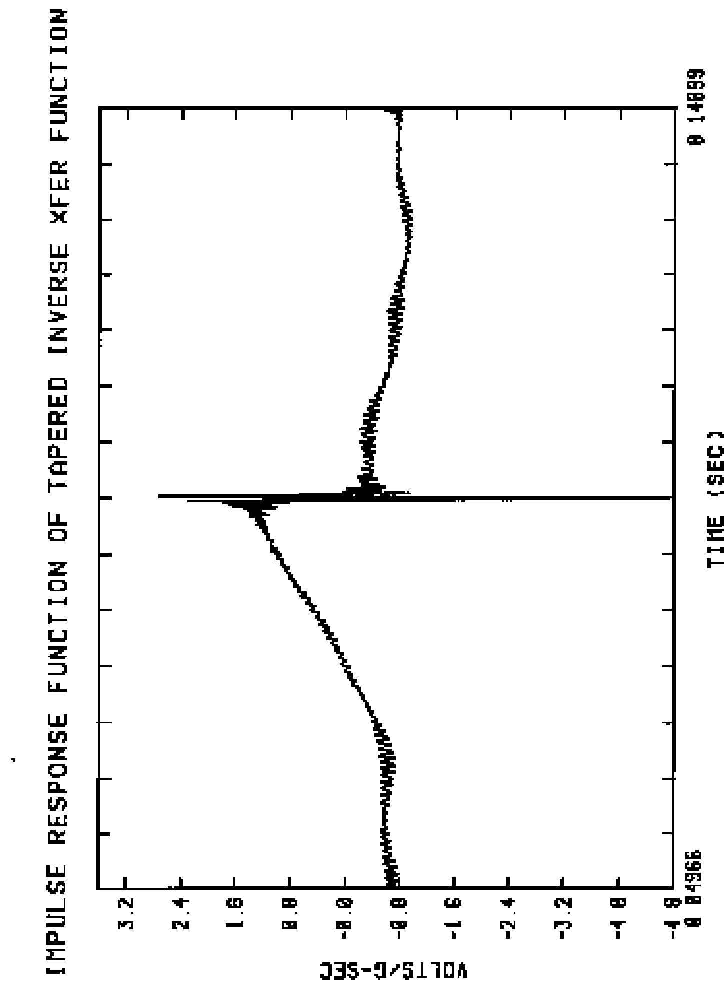
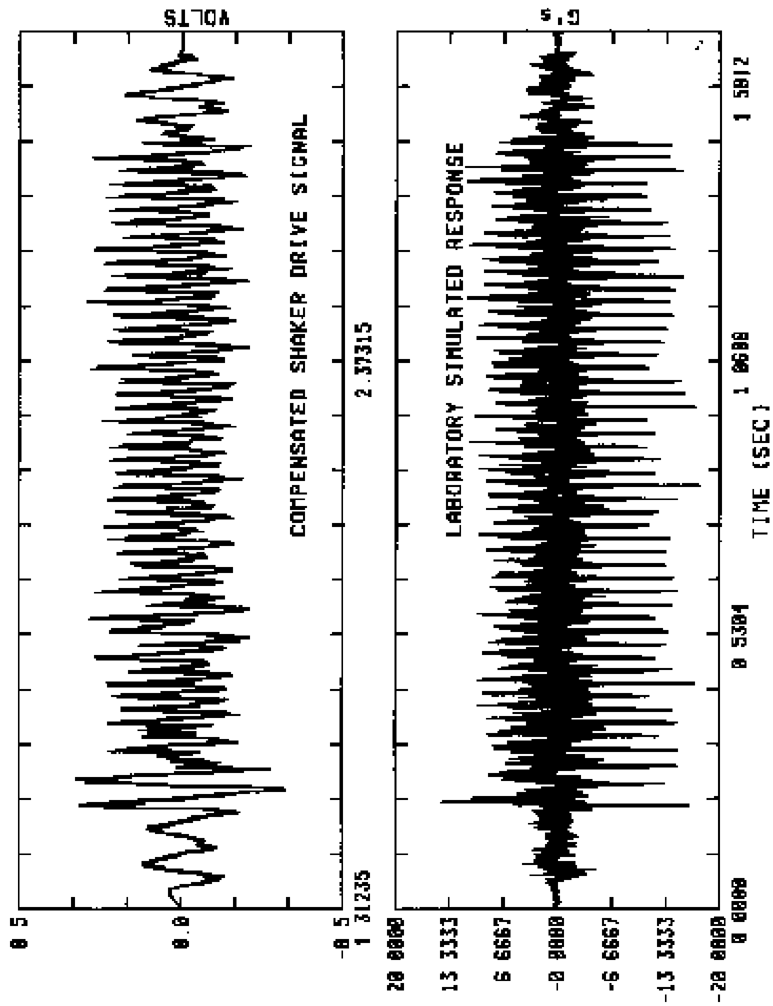


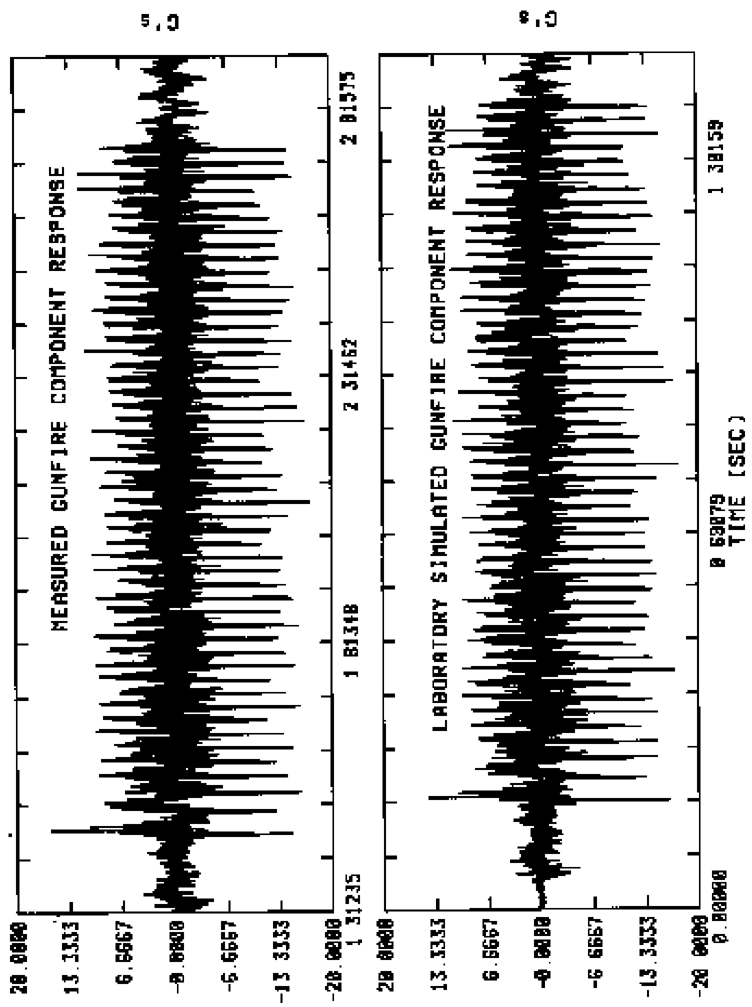
FIGURE A-5. Impulse response function.



a. Drive Signal

b. Materiel Response

FIGURE A-6. Compensated shaker drive signal along with resulting test item response.



a. Measured b. Simulated

FIGURE A-7. Comparison of measured gunfire materiel response with laboratory simulated gunfire test item response.

ANNEX B

STATISTICALLY GENERATED REPETITIVE PULSE

MEAN (DETERMINISTIC) PLUS RESIDUAL (STOCHASTIC) PULSE

1. SCOPE

1.1 Purpose

This Annex provides an overview of a technique for simulation of a time-varying random process given a sample function for the process that can be used to generate ensemble statistics describing the time varying character of the process.

1.2 Application

Details for the technique are found in reference c, other aspects of the technique are found in references d and e; more recent developments are found in references f and g. The stochastic simulation technique to be described here for a single unknown time-varying random process for which a single sample function from the process is available (this single sample function is representative of a single gunfire physical configuration for which extrapolation to other configurations is undetermined).

a) is convenient to implement on a personal computer (PC) used to control a shaker system,

b) has many features analogous to that of traditional stationary time history shaker simulation based on autospectral density estimate specification,

c) is very flexible in terms of the length of statistically equivalent records it can generate for laboratory replication of a in-service measured response environment,

d) has statistics that are easy to interpret and that approximate the true statistical variation in the unknown underlying random process,

e) can be generalized to other forms of time-varying random processes with ensemble representation easily,

f) abandons a minimal number of higher order features of the measured response ensemble not considered essential to conservative in-service measured data replication by way of laboratory test item response simulation testing.

The following paragraphs are directed toward a description of this method of simulation along with some of its limitations.

2. DEVELOPMENT

2.1 Nomenclature

E{ }	expected value of the quantity within the braces
N, N_p	number of pulses in an ensemble
N_s	number of simulated pulses

N_t	number of time points in an ensemble member
P(x,t)	probability distribution function for a nonstationary random process
$R_{xx}(\tau,t)$	nonstationary auto-correlation function
V[ ]	variance of the quantity within the brackets
$\{x_i(t)\}$	random process
$x_i(t)$	ith sample function for a random process, $\{x_i(t)\}$
$X_T(f)$	Finite Fourier Transform of x(t) over an interval of time T
$\mu_x(t)$	true time-varying mean
$\hat{\mu}_x(t)$	time-varying mean estimate
$\sigma_x(t)$	true time-varying standard deviation
$\hat{\sigma}_x(t)$	time-varying standard deviation estimate
$\Psi_x^2(t)$	true time-varying mean square
$\hat{\Psi}_x^2(t)$	time-varying mean square estimate
T_p	period in seconds of a stationary sample record
f_1=1/Tp	fundamental frequency of a stationary sample record in Hertz
T	sampling time interval
f_c=1/(2T)	Nyquist cutoff frequency

2.2 Introduction

In all that follows the term "ensemble" is taken to mean a collection of sample time history records defined over a specific time interval. In the case of a nonstationary environment, the only complete description of the environment is given through (1) statistical estimates of all the probabilistic moments of the process as a function of amplitude and time from the specification of P(x,t) or (2) a statistical estimate of the time-varying auto-correlation function $R(\tau,t)$. Generally P(x,t) and $R(\tau,t)$ are not available either directly in an analytic form or through accurate estimate based on the limited in-service measured response data. For practical purposes, for an in-service measured environment estimating the (1) time-varying mean, (2) time-varying standard deviation, (3) time-varying root mean square, (4) overall average energy spectral density, and (5) time-varying autocorrelation, assist in characterizing the nonstationary random process from which the sample ensemble is created. Replication of some or all of these measured ensemble estimates in the simulation process will, in general, provide a satisfactory nonstationary test simulation of the in-service environment.

2.3 Assumptions

In what follows it is assumed that acceleration is the materiel response measurement variable, however, other measurement variables, e.g., strain, may be just as useful, provided, they are capable of capturing the characteristic amplitude/frequency range of interest.

To assist the practitioner in deciding if the procedures described in this annex are applicable to particular measurement/test objectives, the following basic assumptions are made.

The in-service measured materiel response is obtained from measurements at "hard points" on the materiel to be tested. This term "hard point" implies that (a) local materiel response peculiar to the location of the measurement instrumentation (including structural nonlinearity) is not dominant in the materiel response measurement and (b) measured materiel response at the selected point is representative of the overall materiel response.

A sample time history trace of the measured in-service materiel response shows a distinct time-varying quality that repeats in a time interval correlated with the firing rate of the gun.

A sample time history of the measured in-service materiel response may be decomposed into an ensemble of shorter time history records (or pulses) having similar time-varying characteristics at equal time intervals from the beginning of each of the shorter time history records (exact method of decomposition of the sample time history record is left to the discretion of the analyst - this usually can be accomplished by examining the measured "timing" or "firing" pulse for a repeated event or by way of cross-correlation methods as applied to the sample time history).

For testing, configuration information for the test item similar to that configuration for which the measured in-service response data is available.

Use of the procedures outlined in annex A for Direct Reproduction of Field Measured Materiel Response Data for determination of the test frequency response function for electrodynamic shaker (vibration exciter).

Application of the test frequency response function to the simulated amplitude time history may be accomplished through (a) an energy spectral density function formulation whereby each short time history or pulse is individually compensated by way of the convolution of the pulse time history with the system impulse response function and the pulses concatenated into one long output voltage time history for input to the digital-to-analog interface or (b) a long time history convolution, whereby the uncompensated long output time history is first generated and then convolved with the system impulse response function to provide the compensated voltage drive signal for input to the digital-to-analog interface. Both of these techniques assume generation of a long compensated voltage waveform to be run in an open loop form on a shaker system. For this open loop run configuration, it is suggested that the length of the compensated waveform not exceed five seconds and the appropriate abort limits are active on the shaker system. (As sophistication in shaker control systems increases the energy spectral density formulation with waveform compensation on individual pulses and closed loop control will become the norm for operation. At this time practicality of this procedure is limited by the speed of processors in input and output to the shaker system. In addition, (1) a rationale for quantitatively judging the "adequacy" of the simulation in "real time," based on the time-varying statistical estimates, and (2) a means of "real time" compensation of "inadequate" simulation "in real time", has not been developed.)

The adequacy of the simulation in meeting the specification on the difference or error between the measured in-service materiel response statistics and the measured test item response from the test simulation is based upon utilizing equivalent sample sizes or correcting the error measure based on sample size differences.

In summary, at the time of this writing, the test simulation of a measured in-service materiel response is based on:

- pretest generation of the uncompensated test sample time history,
- compensation of the test sample time history,
- open loop control for the shaker system,

- off line processing of the test item response sample time history for direct comparison with measured in-service materiel response sample time history.

2.4 Modeling and Statistics for Description of a Materiel Response Time-Varying Random Process

A very general model for modeling a time-varying random process is the "product model", which assumes in its most basic form, that the time-varying characteristics of a random process can be separated from the frequency characteristics of the random process (see reference b). From materiel response to gunfire a form of product model can be used to adequately describe this response. The procedures used in constructing the model require some experience. Unfortunately, this modeling does not provide for parameterized predictions of materiel response in other measured data configurations. The basic statistics to be used to characterize a measured response environment with an ensemble representation are the following /

a) the time-varying mean,

b) time-varying standard deviation,

c) time-varying root mean square,

d) average energy spectral density function (may be time dependent),

Error statistics for the simulation may be based on the error expressions for a. to d.

Following is a definition of the product model used in this development. Taking t as the continuous time variable, for discrete processing each ensemble member consists of N_t time samples in the time interval $0 \leq t \leq T_p$. Consideration is given to the time-varying frequency character over discrete time intervals, which can be explored in more detail through the nonstationary auto-correlation function. References c, d, and e consider the issue in more detail. Using the notation and terminology from reference b, for u(t) a sample time history from a stationary random process, {u(t)}; and both $a_1(t)$ and $a_2(t)$ deterministic time histories, then a general time-varying random process {x(t)} can be modeled as

$$x(t) = a_1(t) + [a_2(t)\ \ u(t)]_f \qquad \text{(B-1)}$$

$a_1(t)$ is a deterministic time history in terms of the in-service time-varying ensemble mean estimate. $a_2(t)$ is a deterministic time history in terms of the in-service time-varying ensemble standard deviation estimate. The function $a_2(t)$ shapes (in the time domain) the root mean square level of the residuals from the in-service ensemble after $a_1(t)$ has been removed from the in-service ensemble. The "f" following the bracket indicates that the residual information is a function of frequency content and in the description below, f, represents the time-varying frequency content in four discrete and equal length time intervals. For this model $a_1(t)$ - the time-varying mean of the ensemble will be referred to as the "signal" and $[a_2(t)\ (u(t))]_f$ - the shaped residual or "noise". If the time-varying random process is heavily dominated by the deterministic time-varying mean or "signal", i.e., the amplitude of $a_1(t)$ is large in comparison with the residual $[a_2(t)\ (u(t))]_f$, then one should expect comparatively small time domain errors in the time-varying mean, standard deviation and root mean square. The frequency content should also be easily replicated. The residual ensemble constructed by subtracting the time-varying mean from each sample time history of the original ensemble is defined in terms of the in-service measured ensemble as follows:

$$\{r(t)\} = \{x(t) - \hat{\mu}_x(t)\} \qquad \text{(B-2)}$$

This residual ensemble has the following two properties:

- time-varying mean of {r(t)} is zero
- time-varying root mean square of {r(t)} is the time-varying standard deviation of the original ensemble {x(t)}

Time domain criterion for testing the validity of the simulation is given as the variance of the time domain estimators of the time-varying mean, time-varying standard deviation and the time-varying root mean square. Expressions for these estimators and their variance are provided in equations (B-3) through (B-9). The unbiased time-varying mean estimate for an ensemble {x(t)} of N time history samples is given by

$$\hat{m}_x(t) = \frac{1}{N}\sum_{i=1}^{N} x_i(t) \quad 0 \le t \le T_p \qquad \text{(B-3)}$$

and the variance of this estimator is given as

$$V\left[\hat{\mu}_x(t)\right] = E\left[\left(\hat{\mu}_x(t) - \mu_x(t)\right)^2\right] \qquad 0 \le t \le T_p \qquad \text{(B-4)}$$

where $\mu_x(t)$ is the true nonstationary time-varying mean of the process.

The time-varying standard deviation estimate for this ensemble {x(t)} is given by

$$\hat{s}_x(t) = \sqrt{\frac{\sum_{i=1}^{N}\left[x_i(t) - \hat{m}_x(t)\right]^2}{N-1}} \qquad 0 \le t \le T_p \qquad \text{(B-5)}$$

and the variance of this estimator can be given in its theoretical form as

$$V\left[\hat{\sigma}_x\right] = E\left[\{\hat{\sigma}_x(t) - \sigma_x(t)\}^2\right] \quad 0 \le t \le T_p \qquad \text{(B-6)}$$

where $\sigma_x(t)$ is the true nonstationary time-varying standard deviation of the process.

The unbiased time-varying mean squ are estimate for an ensemble {x(t)} is given by

$$\hat{y}_x^2(t) = \frac{1}{N}\sum_{i=1}^{N} x_i^2(t) \quad 0 \le t \le T_p \qquad \text{(B-7)}$$

and the variance of this estimator is given as

$$V\left[\hat{\psi}_x(t)\right] = E\left[\{\hat{\psi}_x^2(t) - \psi_x^2(t)\}^2\right] \qquad 0 \le t \le T_p \qquad \text{(B-8)}$$

where $\psi_x^2(t)$ is the true nonstationary time-varying mean square of the process.

In the frequency domain, the average energy spectral density function for an ensemble {x(t)} is

$$E_{xx}(f) = 2E\left[\left|X_{T_p}(f)\right|^2\right] \qquad 0 \langle f \langle f_c \qquad \text{(B-9)}$$

and the variance of this estimator is given in theoretical form as

$$V[\hat{E}_{xx}(f)] = E[\{\hat{E}_{xx}(f) - E_{xx}(f)\}^2] \qquad 0 \langle f \langle f_c \qquad \text{(B-10)}$$

In computing these estimates of error (or just quantitatively measuring how "close" the test simulation materiel response is to in-service materiel response) the "true" quantities are unknown but can be taken as the processed in-service measured materiel response.

2.5 Specific Application of the Model to the Measured Materiel Response

This portion of the Annex provides a brief overview of the actual processing necessary to perform a successful stochastic materiel response simulation to a measured in-service materiel response environment. The in-service measured materiel response to be modeled is a fifty pulse (N_p=50) round 30 mm gunfire event depicted in Figure B-1a. The gun-firing rate is approximately 40 rounds per second and the event lasts for about 1.25 seconds. This record is subsequently digitized at 20,480 samples per second with an anti-alias filter set at 2kHz. It is clear just from visual inspection of the amplitude time history that it has periodic time-varying characteristics. This record is carefully decomposed into an ensemble of 50 pulses each of about 25 milliseconds length for which classical time-varying statistical techniques are applied. Figure B-2a contains the plot of a typical pulse of the ensemble (pulse 37) and figure B-3a contains its residual. Figure B-4a contains a plot of the mean estimate for this ensemble defined in equation (B-3). The standard deviation estimate of the ensemble of N records defined in equation (B-5)) is shown in figure B-5a. This is also the root mean square of the residual ensemble. Figure B-6a contains a plot of the root mean square for the ensemble. By subtracting the mean from each member of the ensemble, a residual ensemble is obtained. This residual ensemble has zero mean and a non-zero time-varying root mean square the same as the standard deviation of the original ensemble. It is very important to understand the characteristics of this residual ensemble. It should be clear from the above figures that the measured ensemble has a time-varying mean, a time-varying mean square and a time-varying frequency with higher frequencies in the initial portion of the record. An energy spectral density computed on the original measured ensemble and the measured residual ensemble reveals the effect of removal of the time-varying mean from the original ensemble and the differing frequency characteristics of the two ensembles. Figure B-7a provides a superposition of both of the energy spectral density estimates. The filter bandwidth for the ESD estimates is 5 Hz. An even more dramatic depiction of the time frequency character of the original ensemble is given in Figure B-8a, T1 through T4. In this analysis the pulse length is divided into four equal time segments of 6.25 ms each and the average ESD computed for each segment retaining a 20 Hz filter bandwidth. The estimates are averaged over the ensemble with no time domain tapering applied. When all four spectra are superimposed upon one another, it is clear that the variation of frequency with time is substantial both for the original ensemble and for the residual ensemble in figure B-9. The residual ensemble is studied for its second order or correlation properties in references c, d and e. The actual steps used to perform the simulation according to the model outlined in figure (B-1) and to estimate the error in the time-varying mean, standard deviation, root mean square, and the partial and overall energy spectrum estimate are contained in Reference c. Figures B-10a and 10b depict the deterministic function $a_1(t)$ and the estimate function $a_2(t)$, respectively. Figure B-11a displays the residual information before the residual is filtered and figure B-11b the residual after filtering is applied. Using information from references a and b only, Fourier based (FFT and inverse FFT) is used to determine the simulated test ensemble. Segmentation in time in order to simulate the time-varying frequency characteristics of the ensemble did provide for some minor discontinuities at the time interval boundaries in the simulation. From reference e it can be noted that it is also possible to segment the time-varying characteristics in the frequency domain which also results in some minor discontinuities in the frequency domain. The results of the simulation are displayed in the figures below in order to allow the practitioner to note the general fidelity in the simulation. Figure B-1b represents a simulated ensemble with N_p pulses to give an overall qualitative assessment of the simulation. Figure B-2b and figure B-3b provide plots of a typical pulse (pulse number 37) and its residual from this simulated ensemble, respectively. Figure B-4b is the mean for the ensemble with figure B-5b the standard deviation, and figure B-6b the root mean square. Figures B-7 through B-9 display measured information with corresponding simulated information. Figure B-12 contains the maximum, the median time-varying root variance estimates for the time-varying mean for sample sizes of 10, 25 and 50 pulses. This represents the error that might be expected at each time point as a result of the simulation of the three sizes of the ensembles. Corresponding information is provided in figure B-13 for the time-varying standard deviation and in figure B-14 for the time-varying root mean square. In general for an ensemble with N_p sample time histories the maximum root variance is less than 2.5g's with the median being below 0.75g's. These plots for the most part display some degree of uniformity over the time interval.

2.6 Implementation

The technique outlined above may be implemented by pre-processing the data and generating the simulated materiel response ensemble on a mainframe computer or a PC. In either case, the simulated digital waveform must be appropriately compensated by the procedure described in Appendix A before the analog voltage signal to the shaker is output. This technique of stochastic simulation is quite elaborate in detail but does provide for a true stochastic time-varying laboratory simulation of materiel response based on measured in-service materiel response. The technique is flexible, in that it can produce an unlimited number of "pulses" all slightly different with testing limited only by the length of time a shaker controller can provide an adequate simulation in an open loop mode of control. If it is assumed that shaker output and test item response scale linearly with shaker master gain, degrees of test conservativeness in the stochastic simulation may be introduced.

2.7 References/Related Documentation

a) C. Lanczos, Discourse on Fourier Series, Hafner Publishing Company, New York, 1966.

b) J. S. Bendat and A. G. Piersol, Random Data: Analysis and Measurement Procedures, 2nd edition, John Wiley & Sons Inc., New York, 1986.

c) R. G. Merritt, Simulation of Ensemble Oriented Nonstationary Processes, Part 2, Proceedings of 1994 IES 40th Annual Technical Meeting, Chicago, IL, May 1994.

d) R. G. Merritt, An Example of the Analysis of a Sample Nonstationary Time History,Proceedings of 1994 IES 40th Annual Technical Meeting, Chicago, IL, May 1994.

e) D. O. Smallwood, Gunfire Characterization and Simulation Using Temporal Moments, Proceedings of the 65th Shock and Vibration Symposium, Volume 1, San Diego, California, November 1994.

f) D. O. Smallwood, Characterization and Simulation of Gunfire With Wavelets, Proceedings of the 69th Shock and Vibration Symposium, Volume 1, Minneapolis, MN, October 1998.

g) R. G. Merritt, A Note on Prediction of Gunfire Environment Using the Pulse Method,Proceedings of 1999 IEST 45th Annual Technical Meeting, Ontario, California, May 1999.

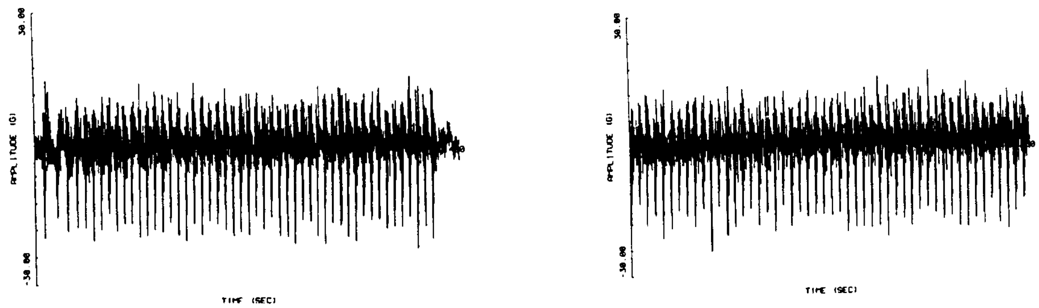
3. RECOMMENDED PROCEDURES

3.1 Recommended Procedures

For single materiel response measurements, on comparatively simple dynamic materiel, use this procedure. This procedure is to be used in cases in which a statistically correct laboratory replication of the response environment is absolutely essential to establish materiel operational and structural integrity under gunfire environment.

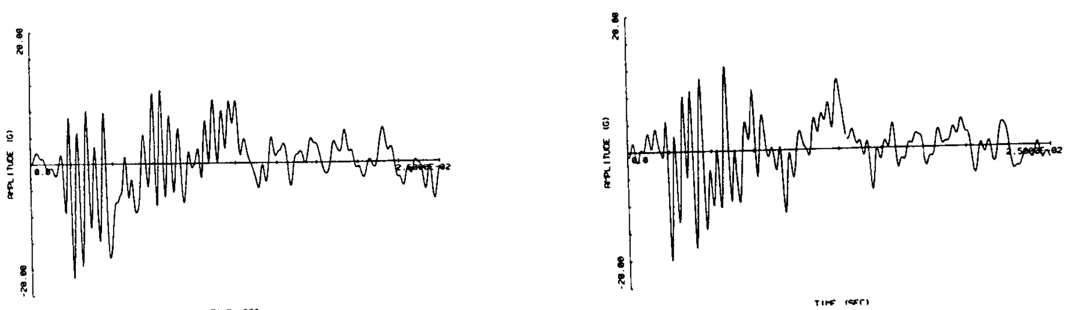
3.2 Uncertainty Factors

The only significant uncertainty in this procedure results in the degree to which the measured environment differs from the actual in-service environment. It is usually not possible to obtain the measured environment under every conceivable in-service condition. The errors in the simulation are independent of the variability of the in-service environment.



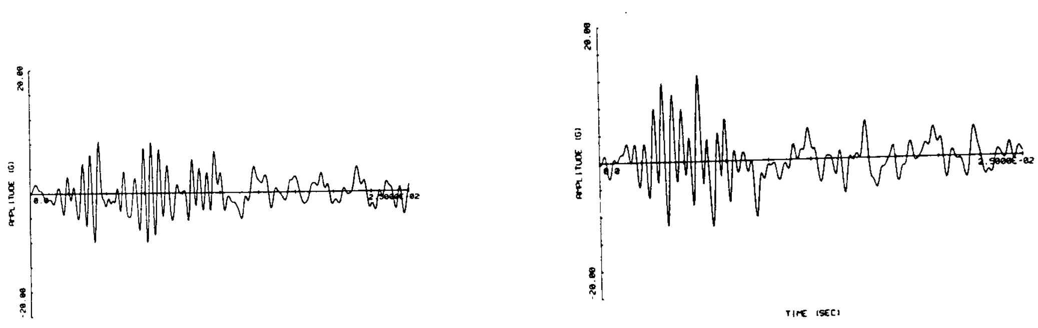
(a) Measured Data (b) Simulated Data

FIGURE B-1 Fifty Round 30 mm Gunfire Event



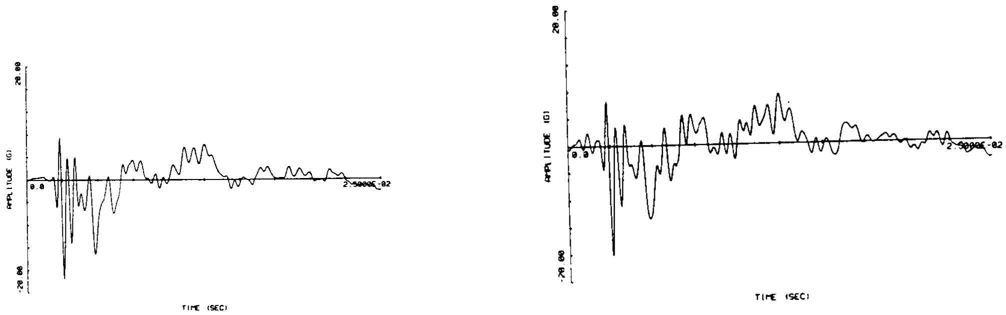
(a) Measured Data (b) Simulated Data

FIGURE B-2 Ensemble Sample Time History Pulse (Pulse 37)



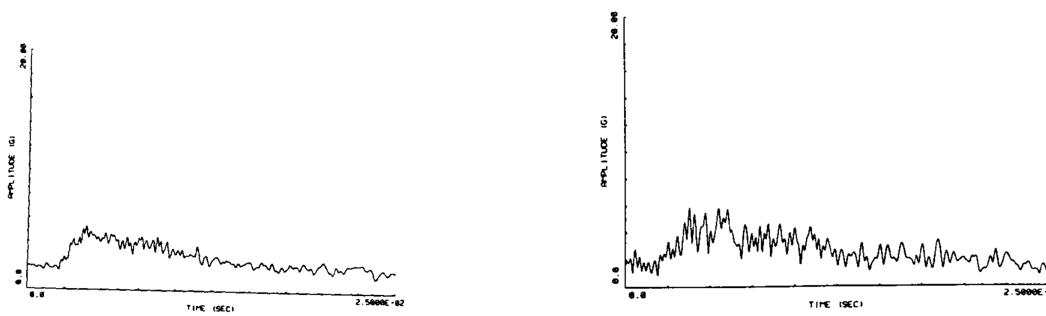
(a) Measured Data (b) Simulated Data

FIGURE B-3 Ensemble Residual Sample Time History Pulse (Pulse 37)



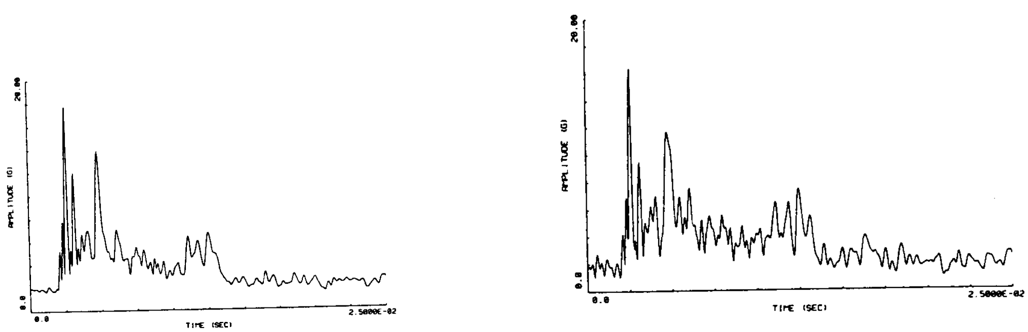
(a) Measured Data (b) Simulated Data

FIGURE B-4 Ensemble Time - Varying Mean Estimate



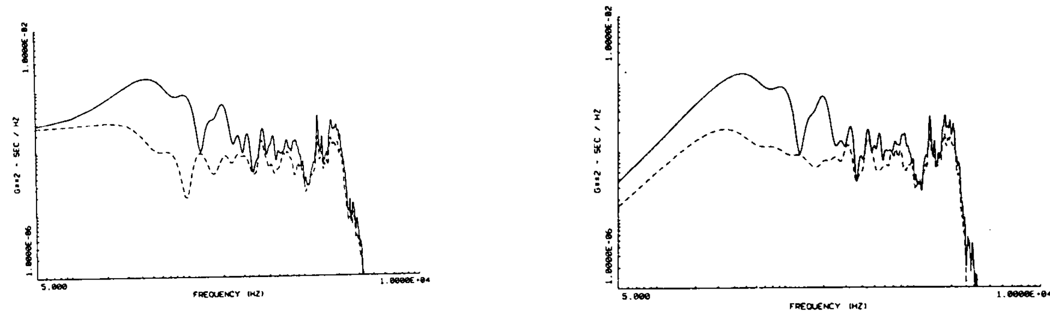
(a) Measured Data (b) Simulated Data

FIGURE B-5 Ensemble Time - Varying Standard Deviation



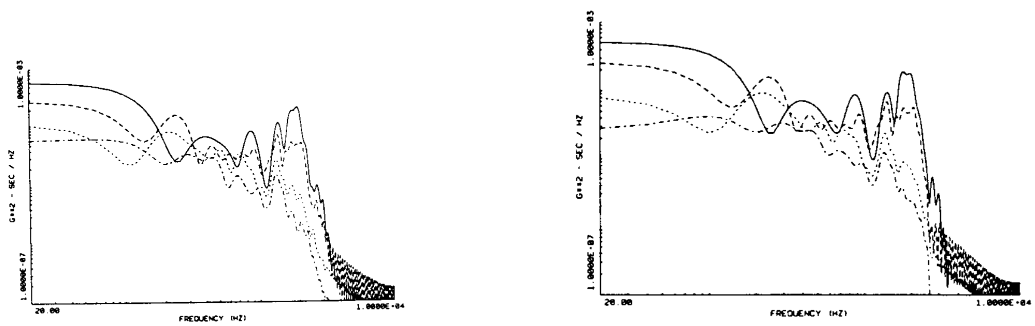
(a) Measured Data (b) Simulated Data

FIGURE B-6 Ensemble Time - Varying Root Mean Square Estimate



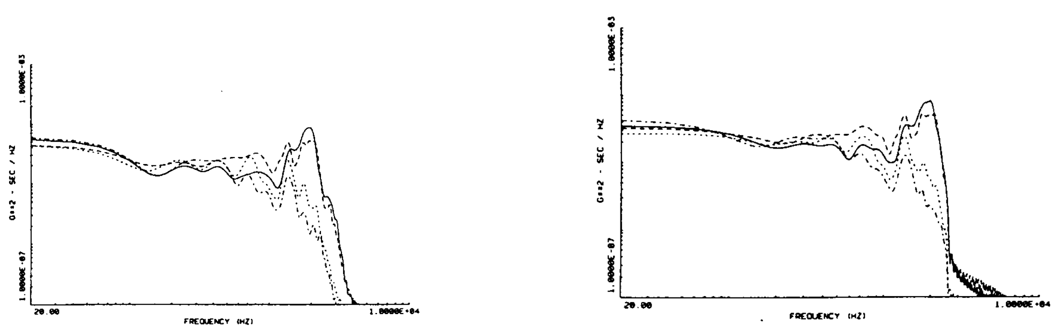
(a) Measured Data Ensemble (b) Simulated Data
Ensemble

FIGURE B -7 Energy Spectral Density Function Estimate



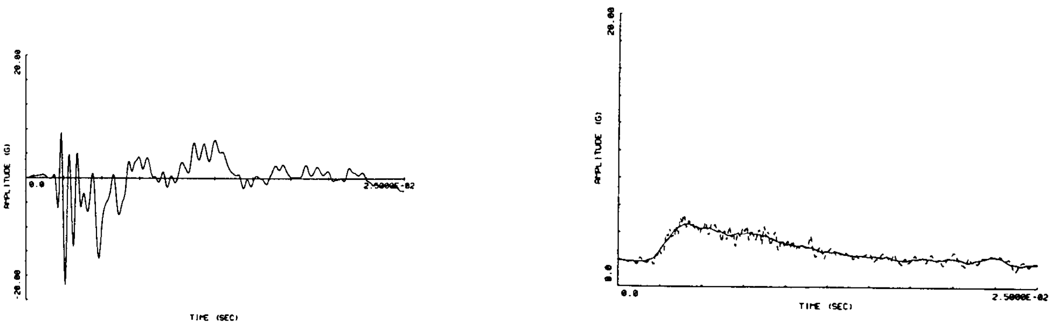
(a) Measured Data Ensemble (b) Simulated Data
Ensemble

FIGURE B-8 Short Time Energy Spectral Density Function Estimate



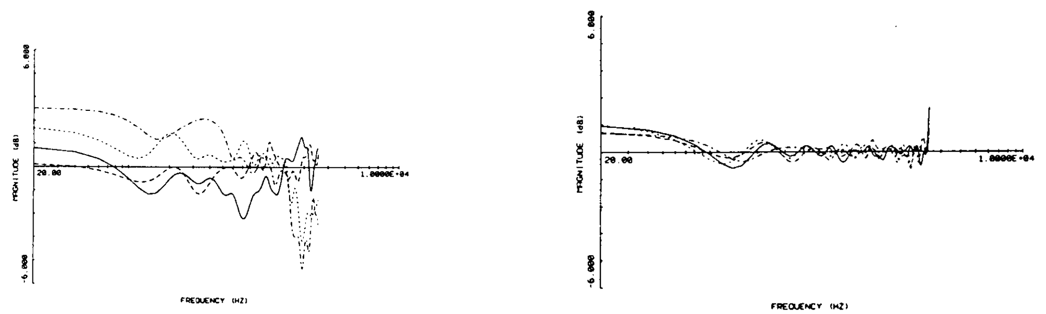
(a) Measured Residual Ensemble (b) Simulated Data Ensemble

FIGURE B-9 Short Time Energy Spectral Density Function Estimate



(a) $a_1(t)$ - Deterministic Signal (b) $a_2(t)$ - Estimate Smoothed Residual window

FIGURE B-10 Nonstationary Model Deterministic Functions



(a) Before Residual Filtering (b) After Residual Filtering

FIGURE B-11 Segmented ESD Ratio

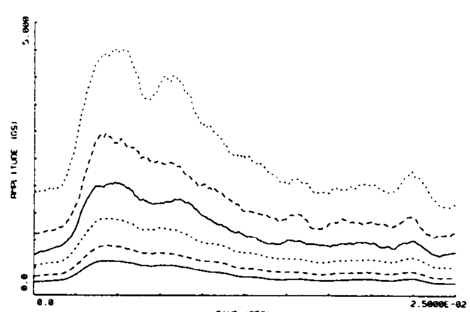


FIGURE B-12 Smoothed simulation root variance estimate for the time-varying mean for simulated ensembles sample sizes of 10, 25, and 50 sample time histories - maximum and median

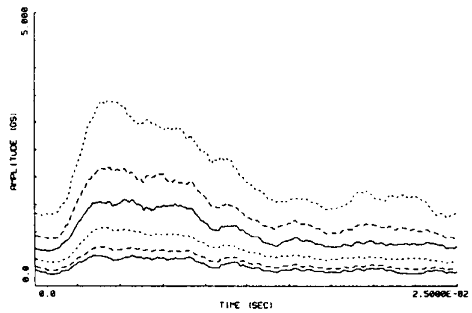


Figure B-13 Smoothed simulation root variance estimates for the time-varying standard deviation for simulated ensemble sample size of 10, 25, and 50 sample time histories – maximum and median

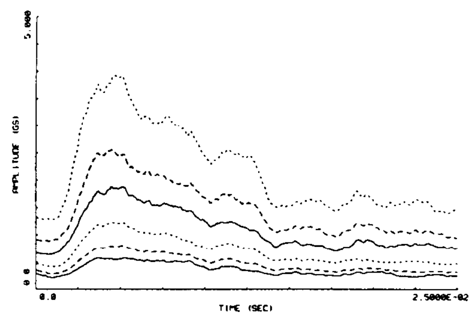


Figure B-14 Smoothed simulation root variance estimate for the time-varying root mean square for simulated ensemble sample size of 10, 25, and 50 sample time histories - maximum and median

ANNEX C

REPETITIVE PULSE SHOCK RESPONSE SPECTRUM (SRS)

1. SCOPE

1.1 Purpose

This annex provides an overview of a technique for laboratory simulation of a gunfire environment based upon a form of “pulse method”.

1.2 Application

The stochastic simulation technique to be described here for a single unknown time-varying random process for which a single sample function from the process is available (this single sample function is representative of a single gunfire physical configuration for which extrapolation to other configurations is undetermined).

a) is convenient to implement on a shaker control system with shock response spectra (SRS) capability,

b) has many features analogous to that of traditional SRS shaker shock simulation based on SRS estimate specification,

c) is very flexible in terms of the length of statistically equivalent records it can generate for laboratory test replication of an in-service measured response environment ,

d) is not restricted to one form of pulse and,

e) abandons a minimal number of higher order features of the measured response ensemble not considered essential to conservative in-service measured response data replication by way of laboratory test item response simulation testing.

The following paragraphs are directed toward an overview of this method of test item response simulation along with its limitations.

2. DEVELOPMENT

2.1 Introduction

The SRS method assumes that the measured materiel response time history can be decomposed into an ensemble of individual pulses. Maximax shock response spectra are computed over the ensemble of pulses using various damping factors to assist in characterizing the frequency content of the individual pulses. The shock response spectrum mean is also computed over the ensemble of pulses for each damping factor to further characterize the materiel response pulses. Using the information from the shock response spectra, an acceleration time history is synthesized using amplitude modulated sine components (“wavelets”) or damped sinusoids. The SRS based acceleration response time history is then used as the characteristic gunfire materiel response pulse, and input to the test item at the firing rate of the gun (see references b and c).

2.1.1 Advantages of this procedure are:

a) It makes use of standard laboratory shaker shock test equipment,

b) The method reproduces the frequency characteristics of the measured materiel response data,

c) The SRS can easily specified in documents and reproduced at various test facilities.

2.1.2 Disadvantages of this procedure are:

a) The character of the time history generated by the "wavelets" or damped sinusoids is not well controlled and may not appear similar in form to the measured materiel response pulses,

b) Little or no statistical variation can be easily introduced into the simulation, and

c) Reproducing the series of pulses at the firing rate of the gun may present a problem for shaker control systems not designed for this mode of operation.

A particular example of gunfire materiel response simulation using the Repetitive Pulse Shock Response Spectrum (SRS) method is discussed below. This procedure is performed using a digital vibration control system with SRS testing capability (see references b and c).

2.2 Test Configuration

An instrumented test item is installed in a laboratory vibration fixture and mounted to the armature of an electrodynamic shaker. The test item employed during the laboratory simulation is of the same configuration as the materiel used to collect the in-service measured response data. A piezoelectric accelerometer is installed internal to the test item for purposes of acceleration response measurement.

2.3 Creating a Digital File of the Gunfire Vibration Response

The first step in this simulation process is to digitize the measured in-service materiel response data to obtain an acceleration time history (Figure C-1). Digital processing of the analog data is performed using a 2kHz, 48dB/octave low pass anti-alias filter (digital file is DC coupled and not high pass filtered) and a sample rate of 20,480 samples per second for good time history peak resolution. The anti-alias filter should have linear phase characteristics.

2.4 Computing the Shock Response Spectra

If examination of the individual measured response pulses indicates similar character between the pulses, a representative pulse is chosen for analysis. SRS is then computed over the representative pulse using a specified analysis Q of 10, 25, 50, and 100. To increase the statistical confidence in the results the pulse sequence may be ensemble averaged in time, the "mean" of the ensemble taken as the representative pulse, and the procedure above applied. The SRS used in the procedure may also be taken to be the mean SRS of the entire pulse individual SRS's. If pulse characteristics are very dissimilar, then it may be necessary to run several tests depending upon the judgement of an experienced analyst.

2.5 Estimating Equivalent Half-cycle Content of Representative Gunfire Materiel Response Pulse

Figure C-2 shows that the representative gunfire materiel response pulse contains seven predominant frequencies at around 80, 280, 440, 600, 760, 1,360, and 1,800-Hz. Since (2Q) half-cycles for a constant amplitude sine wave provides approximately 95% of the maximum SRS amplitude for a given SRS Q value, an estimate of the equivalent half-cycle content that makes up the predominant frequencies contained in the measured gunfire response can be determined by identifying the Q at which the peak acceleration for a particular frequency of the SRS begins to level off. A Q of 10 in Figure C-2 characterizes the half-cycle content of the 80-Hz component. The half-cycle content of the other predominant frequencies, except at 1,800-Hz, is represented by a Q of 25. A Q of 50 quantifies the half-cycle content of the 1,800-Hz component.

2.6 Generating SRS Transient For Gunfire Materiel Response Pulse Representative

After estimating the frequency content of the representative gunfire materiel response pulse, a SRS transient time history pulse is generated using a digital shaker control system (by means of a proprietary wave synthesis algorithm). The SRS transient time history pulse is composed of 1/12-octave wavelets, with the majority of the 1/12-octave components limited to three half-cycles (that is the minimum allowed for the shaker control system). The seven predominant frequencies are restricted for half-cycle content by either the 25-millisecond duration of the gunfire response pulse (40-Hz gun firing rate) or by the half-cycle estimation technique discussed in Annex C, paragraph 2.5. A Q of 10 is identified for the 80-Hz component; a Q of 25 for the 280-, 440-, 600-, 760-, and 1,360-Hz components; and a Q of 50 for the 1,800-Hz component. The shock response spectrum mean is computed over the ensemble of pulses for each damping factor (Q= 10, 25, 50, and 100) to characterize the SRS amplitudes. The mean SRS that is computed using an analysis Q of 50 is then selected to define the SRS amplitude for each frequency component of the simulated materiel response pulse. Zero time delay is specified for each of the 1/12-octave wavelets. Table C-1 provides the wavelet definition for making up the complex transient pulse and Figure C-3 displays the SRS gunfire materiel response complex transient pulse produced from the wavelet definition.

2.7 Simulating the Gunfire Component Response

The final step in the gunfire materiel response simulation is to repeat the SRS gunfire transient at the gun firing rate of 40-Hz. Because of output pulse rate limitations of the shaker control system being used, the 40-Hz firing rate could not be achieved. Figure C-4 is an acceleration time history that illustrates the repetitive character of the SRS gunfire simulation method without shaker controller output pulse rate limitations.

Note: Figure C-4 is generated for illustrative purposes by digitally appending the Figure C-3 SRS materiel response transient pulse at the gun firing rate. If the shaker control system does not allow for such rapid repetition, the waveform control procedure defined in Annex A could be used on a digitally simulated and shaker compensated series of materiel response pulses.

2.8 Reference/Related Documents

a) Handbook for Dynamic Data Acquisition and Analysis, IEST-RP-DTE012.1, Institute of Environmental Sciences and Technology, 940 East Northwest Highway, Mount Prospect, IL60056

b) Merritt R.G. and S. R. Hertz, Aspects of Gunfire, Part 1. Analysis, NWC Tm 6648 Part 1, October 1990, Naval Weapons Center, China Lake, CA 93555-6100

c) Merritt, R.G. and S. R. Hertz, Aspects of Gunfire, Part 2. Simulation, NWC TM 6648 Part 2,September 1990, Naval Weapons Center, China Lake, CA 93555-6100

3. RECOMMENDED PROCEDURES

3.1 Recommended Procedures

For single point materiel response measurements on comparatively simple dynamic materiel, use this procedure. This procedure is to be used in cases in which laboratory replication of the response environment is essential to establish materiel operational and structural integrity under gunfire environment and for which the test facility is incapable of using procedure 1 and 2.

3.2 Uncertainty Factors

This procedure includes no statistical uncertainty in addition to any uncertainty in the degree to which the measured environment compares with the in-service environment.

TABLE C-1. Wavelet Definition for SRS Gunfire Pulse.

Frequency Hz	Amplitude g	Half-cycles	Frequency Hz	Amplitude g	Half-cycles
78.75	11.995	3	445.45	34.995	21
83.43	11.803	3	471.94	26.455	3
88.39	11.628	3	500.00	19.999	3
93.64	11.455	3	529.73	21.232	3
99.21	11.285	3	561.23	22.568	3
105.11	11.117	3	594.60	23.988	29
111.36	10.952	3	629.96	18.323	3
117.98	10.777	3	667.42	13.996	3
125.00	10.617	3	707.11	20.448	3
132.43	10.459	3	749.15	29.992	37
140.31	10.304	3	793.70	31.225	3
148.65	10.151	3	840.90	32.509	3
157.49	10.000	3	890.90	33.845	3
166.86	10.814	3	943.87	35.237	3
176.78	11.708	3	1,000.00	36.728	3
187.29	12.662	3	1,059.46	38.238	3
198.43	13.709	3	1,122.46	39.811	3
210.22	14.825	3	1,189.21	41.448	3
222.72	16.051	3	1,259.91	43.152	3
235.97	17.358	3	1,334.84	44.975	49
250.00	18.793	3	1,414.21	37.325	3
264.87	20.324	3	1,498.31	31.010	3
280.62	22.004	13	1,587.40	50.003	3
297.30	18.275	3	1,681.79	80.631	3
314.98	16.901	3	1,781.80	130.017	89
333.71	14.825	3	1,887.75	124.882	3
353.55	13.002	3	2,000.00	119.950	3
374.58	16.653	3			
396.85	21.330	3			
420.45	27.321	3			

* Wavelet definition is based upon form of wavelet in proprietary SRS waveform synthesis software

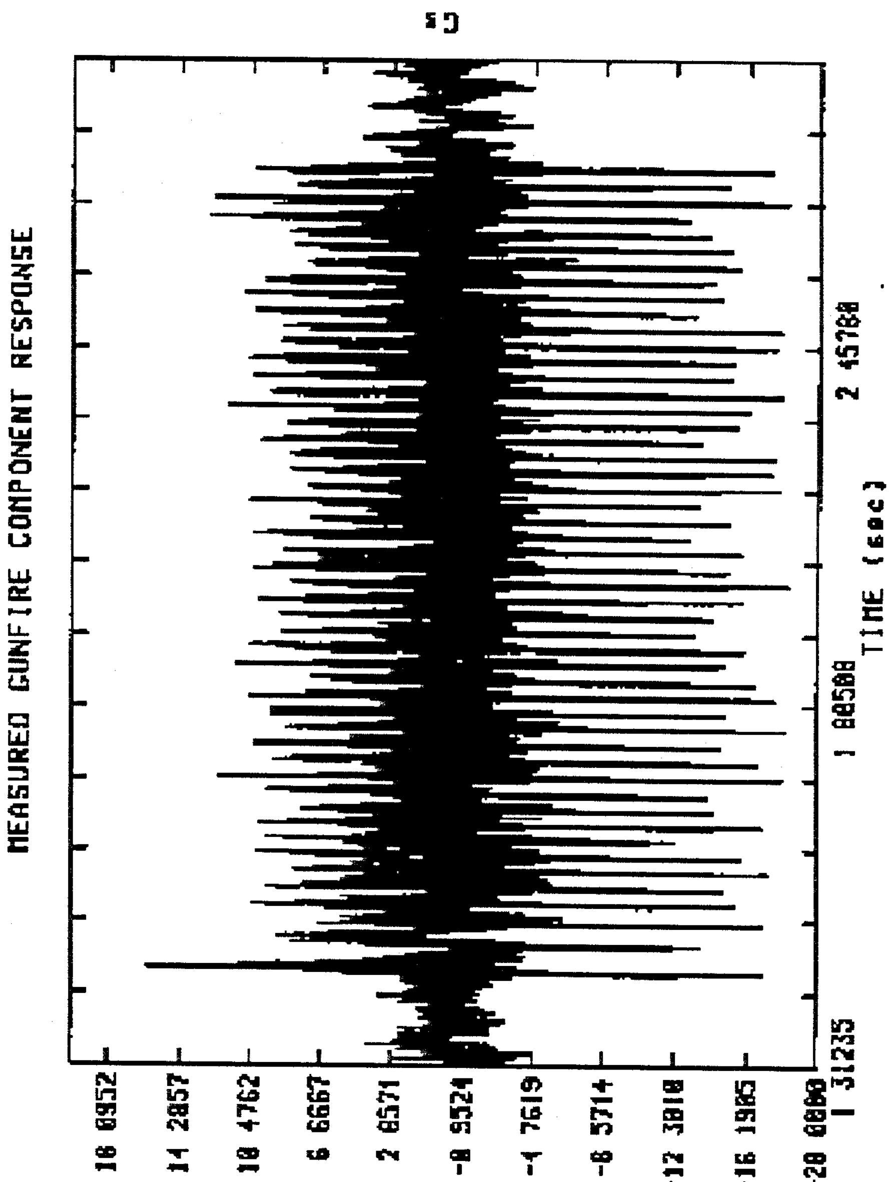


Figure C-1 Digitised flight data

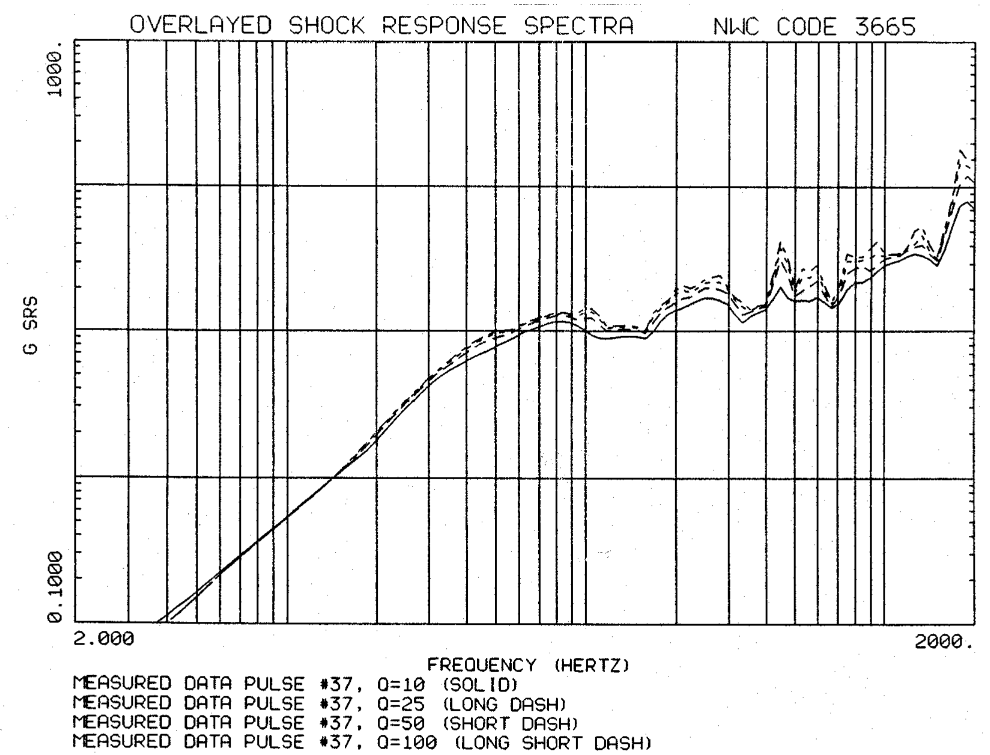


Figure C-2 Comparison of representative gunfire pulse using a Q of 10, 25, 50 and 100

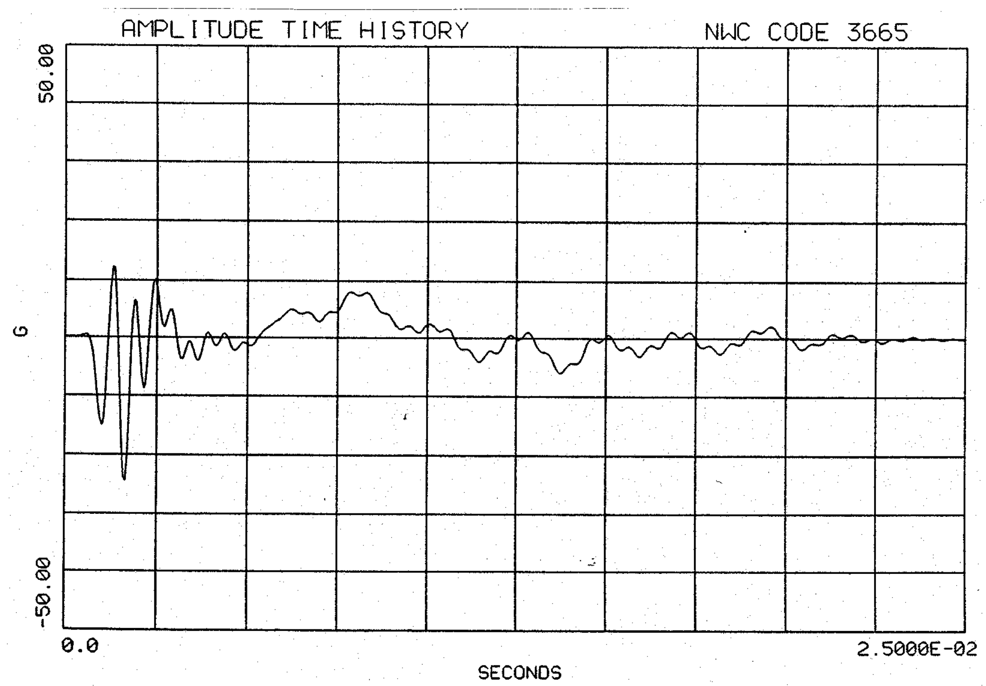


Figure C-3 SRS gunfire pulse generated using a digital controller

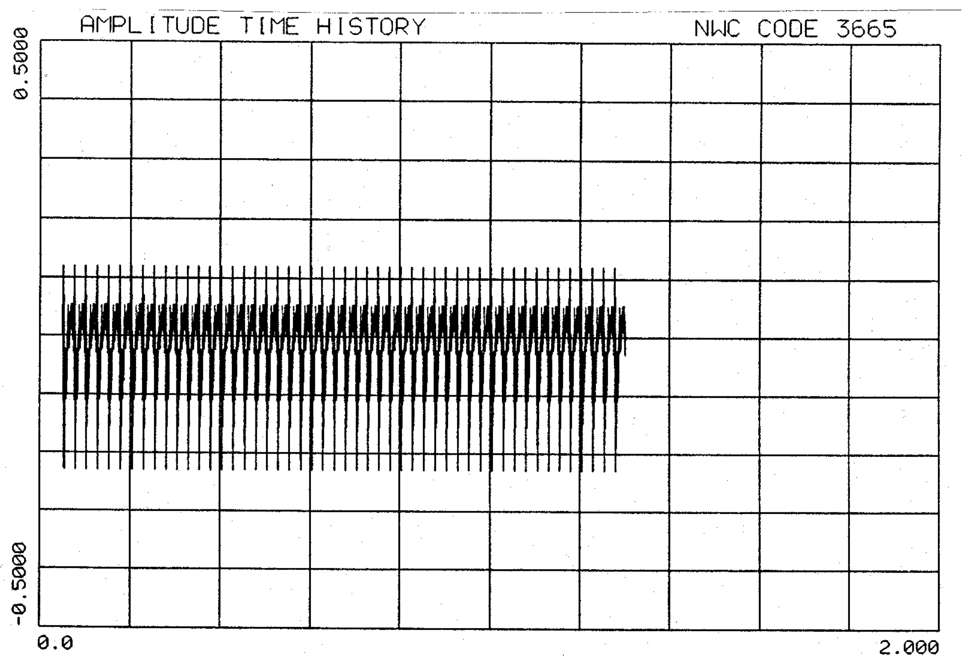


Figure C-4. SRS pulse gunfire simulation

ANNEX D

HIGH LEVEL RANDOM VIBRATION/SINE-ON-RANDOM VIBRATION/NARROWBAND RANDOM-ON-RANDOM VIBRATION (GUIDANCE FOR INITIAL TEST SEVERITIES)

1. SCOPE

1.1 Purpose

This Annex provides the option of utilizing predicted gunfire vibration data (when no measured data is available), to ensure that materiel mounted in an aircraft with onboard guns can withstand the vibration levels caused by:

- pulse overpressures emitting from the muzzle of the gun impinging upon materiel support structure and,
- structure-borne vibration.

This Annex also provides the option for utilizing high level random vibration when the measured data spectrum displays no outstanding discrete harmonic contents.

1.2 Application

This Annex is applicable only for aircraft gunfire and materiel mounted in an aircraft with onboard guns. Guidance in this Annex is to be used only if in-service measured materiel response data is not available or will not be available in the early stages of a development program. This Annex is not intended to justify the use of sine-on-random or narrowband random-on-random for cases in which measured data displays broadband spectra along with components at discrete frequencies. The information in this Annex should be used only if it is vital to the design of the materiel. If there is a possibility of obtaining early measurements of the materiel response mounted on the in-service platform, the severity's developed using the information in this Annex should be supplanted with the severity's estimated from the materiel response under in-service measurement and one of the other procedures used for testing. In particular, if the measured materiel response in-service environment has the character of high level broadband random vibration with no characteristics conducive to application of Procedure II or Procedure III, then:

- apply Procedure I in the form of transient vibration, or,
- submit the materiel to a specified level of high level broadband vibration (based on ASD estimates of the measured in-service materiel response) over a period of time consistent with low cycle fatigue assumptions in accelerated testing or as specified in the Test Instruction (see method 401, Vibration)

2. DEVELOPMENT

2.1 Introduction

This Annex is essentially a reorganised reproduction of the information contained in reference a with some additional guidance. Mention of the “Pulse Method” in I-4.4.1 of reference a has not been included, but is covered in reference b which provides insight into the use of the “Pulse Method” in conjunction with a predictive rationale. References c, d and e provide information relative to the origin of gunfire vibration for aircraft in reference a. Procedure IV differs from the other three procedures in that it is a result of a prediction procedure developed on the basis of an analysis of a comparatively small set of measured gunfire materiel response data. The predicted spectrum therefore provides estimates of materiel vibration response that may be substantially different from in-service measured vibration response of a particular materiel. For a particular materiel and gun/materiel configuration, levels of materiel response to gunfire are generally subject to a large degree of uncertainty. This uncertainty increases substantially in gunfire configurations where the gun is less than a meter from the materiel and the materiel is excited by the gun blast pressure wave.

2.2 Predicting Gunfire Vibration Spectra.

Gunfire prediction spectra consist of a broadband spectrum representative of an ASD estimate from stationary random vibration along with four harmonically related sine waves. Figure D-1 provides a generalized vibration spectrum for gunfire-induced vibration that defines the predicted response of materiel to gunfire environment. Four single frequency harmonically related (sine) vibration peaks superimposed on a broadband random vibration spectrum characterize it. The vibration peaks are the frequencies that correspond to the nominal gunfire rate and the first three harmonics of the gun-firing rate. The specific values for each of the parameters shown in figure D-1 can be determined from table D-I, table D-II and table D-III, and figures D-2 to D-8. The suggested generalized parametric equation for the three levels of broadband random vibration defining the spectrum in figure D-1 is given in dB for g²/Hz (reference to 1 g²/Hz) as:

$$10 \log_{10} T_j = 10 \log_{10} (NF_1E) + H + M + W + J + Bj - 53 \text{ dB} \qquad j = 1, 2, 3 \qquad \text{(D-1)}$$

where the parameters are defined in table D-I. The suggested generalized parametric equation for the four levels of single frequency (sine) vibration defining the spectrum in figure D-1 is given in dB for g²/Hz (reference to 1 g²/Hz) as:

$$10 \text{ LOG}_{10} P_i = 10 \text{ LOG}_{10} T_3 + K_i + 17 \text{ db} \qquad i= 1, 2, 3, 4 \qquad \text{(D-2)}$$

where the parameters are defined in table D-I.

The key geometrical relations used to determine the predicted vibration spectra are the following four geometrical factors:

- Vector distance (D). The vector distance from the muzzle of the gun to the mean distance between materiel support points as shown in Figure D-2. For configurations involving multiple guns, the origin of vector D is determined from the centroidal point of the gun muzzles as shown in Figure D-3. Figure D-7 and figure D-8 provide for spectra reduction factors related to D for the random spectra and the discrete frequency spectra, respectively.
- Gun standoff distance (h). The distance normal to the aircraft's surface as shown in Figure D-4
- Depth parameter (Rs). The distance normal to the aircraft's skin to the materiel location inside the aircraft. If Rs is unknown, use Rs = three inches (See Figure D-2). Figure D-6 provides spectra reduction factors related to Rs.
- Define the gun caliber parameter, c, in millimeters (and inches)

The vibration peaks bandwidths consistent with windowed Fourier processing should be based on in-service measured materiel response data if available. When such in-service data are not available, the vibration peaks bandwidths can be calculated as:

$$BW_{3db} = \frac{\pi\sqrt{F}}{4}$$

for:

BW_{3dB} = the bandwidth at a level 3dB (factor of 2) below the peak ASD level

F = the fundamental frequency (Fi) or one of the harmonics F1, F2, F3, or F4

For cases where the gun firing rate changes during a development program or the gun may be fired at a sweep rate, it is desirable to either

1) perform sinusoidal sweeps within the proposed bandwidth for the fundamental and each harmonic or
2) apply narrowband random vibration levels provided the sweep frequency bandwidth is not too large.

This technique may over-predict those frequencies where the attachment structure or materiel response becomes significantly nonlinear. Likewise, for those cases in which the attachment structure or materiel resonances coincide with the frequencies in the gunfire environment, the materiel vibration response could be under-predicted. The practitioner should clearly understand the options available and inherent limitations in the vibration control system software.

2.3 Duration of Test

Use duration for the gunfire test in each of the three axes, equivalent to the expected total time the materiel will experience the environment in-service. This duration may be conservatively estimated by multiplying the expected number of aircraft sorties in which the gun firing will occur by the maximum amount of time that gun firing can occur in each sortie. The number of sorties in which gunfire will occur will be associated with planned aircraft training and combat utilization rates, but will generally be in the vicinity of 200 to 300 sorties. The maximum gunfire time of gunfire per sortie can be determined from Table D-II by dividing total rounds per aircraft by the firing rate. When a gun has more than one firing rate, perform the test using both firing rates, with test time at each firing rate based on the expected proportion of time at each firing rate for in-service use. The guns carried by an aircraft are generally fired in short bursts that last a few seconds. Testing to a gunfire environment should reflect a form of in-service use in compliance with the Test Instruction. For example, vibration could be applied for two-seconds followed by an eight rest period during which no vibration is applied. This two-second-on/eight second-off cycle is repeated until the total vibration time equals that determined for the aircraft type and its in-service use. This cycling will prevent the occurrence of unrealistic failure modes due to vibration isolator overheating or buildup of materiel response in continuous vibration. Intermittent vibration can be achieved by several means including

1) the interruption of the shaker input signal and
2) a waveform replication strategy for transient vibration discussed in Annex A, storing segments of acceleration time history inputs on magnetic disc or tape.

2.4 Spectrum Generation Techniques

Gunfire materiel response is characterized by broadband random vibration with four vibration peaks that occur at the first three harmonics and the fundamental frequency of the firing rate of the onboard guns. Virtually all modern vibration control system software packages contain a provision for performing a gunfire vibration test based on this form of predicted sine-on-random spectra. The details of these software packages are in general proprietary, but the practitioner is expected to have a clear understanding of the capabilities and limitations of the software. On occasion it has been noted that the dynamic range required to produce and control a specified gunfire spectrum is beyond the ability of some available vibration controllers. A way of solving this problem is to enter into the vibration controller the desired broadband random spectrum with its strong vibration peaks. At those frequencies that have the intense vibration peaks, sine waves can be electronically added to the input of the vibration shaker amplifier. Ensure the amplitude of these sine waves is such that the vibration level produced at those frequencies is slightly less than the desired spectrum level. The vibration controller can make the final adjustment to achieve the needed test level. It is important to note that P_i is in terms of g^2/Hz and not g's. Care must be exercised in specifying the amplitude of the sine waves in g or equivalent input voltage corresponding to a g level. This means of environment replication allows the gunfire test to be done closed loop with commonly available laboratory test equipment and control system software.

2.5 Reference/Related documents

a) MIL-STD-810E Method 514.4, July 1989

b) Merritt, R.G., A Note on Prediction of Gunfire Environment Using the Pulse Method, IEST, 40th ATM, Ontario, CA, May 1999.

c) Sevy, R. W., and E. E. Ruddell, Low and High Frequency Aircraft Gunfire Vibration and Prediction and Laboratory Simulation, AFFDL-TR-74-123, December 1975, DTIC number AD-A023-619.

d) Sevy, R. W., and J. Clark, Aircraft Gunfire Vibration, AFFDL-TR-70-131, November 1970, DTICnumber AD-881-879.

e) Smith, L.G., Vibration Qualification of Equipment Mounted in Turboprop Aircraft, Shock and Vibration Bulletin, Part 2, May 1981.

3. RECOMMENDED PROCEDURES

3.1 Recommended Procedure

For aircraft vibration for equipment mounted in the aircraft with no available measured data use this procedure with the prediction methodology.

3.2 Uncertainty Factors

This procedure includes substantial uncertainty in general levels because of the sensitivity of the gunfire environment to gun parameters and geometrical configuration. It may be appropriate to increase levels or durations in order to add a degree of conservativeness to the testing. Change in levels, durations, or both for the sake of increasing test conservativeness must be supported by rationale and environment assessment documentation. Since extreme spectra prediction levels do not necessarily provide test inputs that correlate with measured data for the same geometrical configuration, the uncertainty in damage potential is increased substantially as the predicted spectra increase level, i. e. testing with this procedure may be quite unconservative.

TABLE D-I.

Suggested generalized parametric equations for gunfire-induced vibration.

$$10 \log_{10} T_j = 10 \log_{10} (NF_1 E) + H + M + W + J + Bj - 53 \text{ dB}$$
$$10 \log_{10} P_i = 10 \log_{10} T_3 + K_i + 17 \text{ dB}$$

For

N =	Maximum number of closely spaced guns firing together. For guns that are dispersed on the host aircraft, such as in wing roots and in gun pods, separate gunfire vibration test spectra are determined for each gun location. The vibration levels, for test purposes, are selected for the gun that produces the maximum vibration levels.
E =	Blast energy of gun (see Table D-III).
H =	Effect of gun standoff distance, h (see Figure D-4).
M =	Effect of gun location M = 0 unless a plane normal to the axis of the gun barrel and located at the muzzle of the gun does not intersect the aircraft structure, then M = -6 dB.
W =	Effect of the weight of the equipment to be tested (use Figure D-5). If weight of materiel is unknown, use W = 4.5 kilograms.
J =	Effect of equipment's location relative to air vehicle's skin (use Figures D-2 and D-6).
Bj =	Effect of vector distance from gun muzzle to materiel location (see Figure D-7).
Fi =	Gunfiring rate where F1 = fundamental frequency from Table D-II. (F2 = 2F1, F3 = 3F1, F4 = 4F1)
Tj =	Test level in g2/Hz. J = 1, 2, 3
Pi =	Test level for frequency Fi in g2/Hz (where i = 1 to 4).
Ki =	Effect of vector distance on each vibration peak, Pi (see Figure D-8).

Note: These equations are in metric units. The resultant dB values are relative to 1 g^2/Hz.

TABLE D-2.
Typical gun configurations associated with aircraft classes.

Aircraft/Pod	Gun (Quantity)	Location	Firing Rate		Rounds Capacity
			Rnds/Min	Rnds/Sec	
A-4	MK 12(2)	WING ROOTS	1000	16.6	100/GUN
A-7D	M61A1 (1)	Nose, left side	4000 & 6000	66.6 & 100	1020
A-10	GAU-8/A (1)	Nose	2100 & 4200	35 & 70	1175
A-37	GAU-2B/A (1)	Nose	6000	100	1500
F-4	M61A1 (1)	Nose	4000 & 6000	66.6 & 100	638
F-5E	M39 (2)	Nose	3000	50	300/gun
F-14	M61A1 (1)	Left side of nose	4000 & 6000	66.6 & 100	676
F-15	M61A1 (1)	Right wing root	4000 & 6000	66.6 & 100	940
F-16	M61A1 (1)	Left wing root	6000	100	510
F-18	M61A1 (1)	Top center of nose	4000 & 6000	66.6 & 100	570
F-111	M61A1 (1)	Underside of fuselage	5000	83.3	2084
MIRAGE	DEFA 554		1200 & 1800	20 & 30	
RAFALE	DEFA 791B		2520	42	
GEPOD 30	GE430 (1) (GAU-8/A)	POD	2400	40	350
SUU-11/A	GAU-2B/A (1)	POD	3000 & 6000	50 & 100	1500
SUU-12/A	AN-M3 (1)	POD	1200	19	750
SUU-16/A	M61A1 (1)	POD	6000	100	1200
SUU-23/A	GAU-4/A (1)	POD	6000	100	1200

TABLE D-III.
Gun specifications.

GUN	GUN CALIBER (mm)	GUN CALIBER (in)	BLAST ENERGY, E (J)*
GAU-2B/A	7.62	.30	6,700
GAU-4/A	20	.79	74,600
GAU-8/A	30	1.18	307,500
AN-M3	12.7	.50	26.000
M3	20	.79	83.000
M24	20	.79	80.500
M39	20	.79	74.600
M61A1	20	.79	74.600
MK11	20	.79	86.500
MK12	20	.79	86.500
DEFA 554	30	1.18	125.000
DEFA 791B	30	1.18	245.000

* joules (J) x 0.7376 = foot-pounds

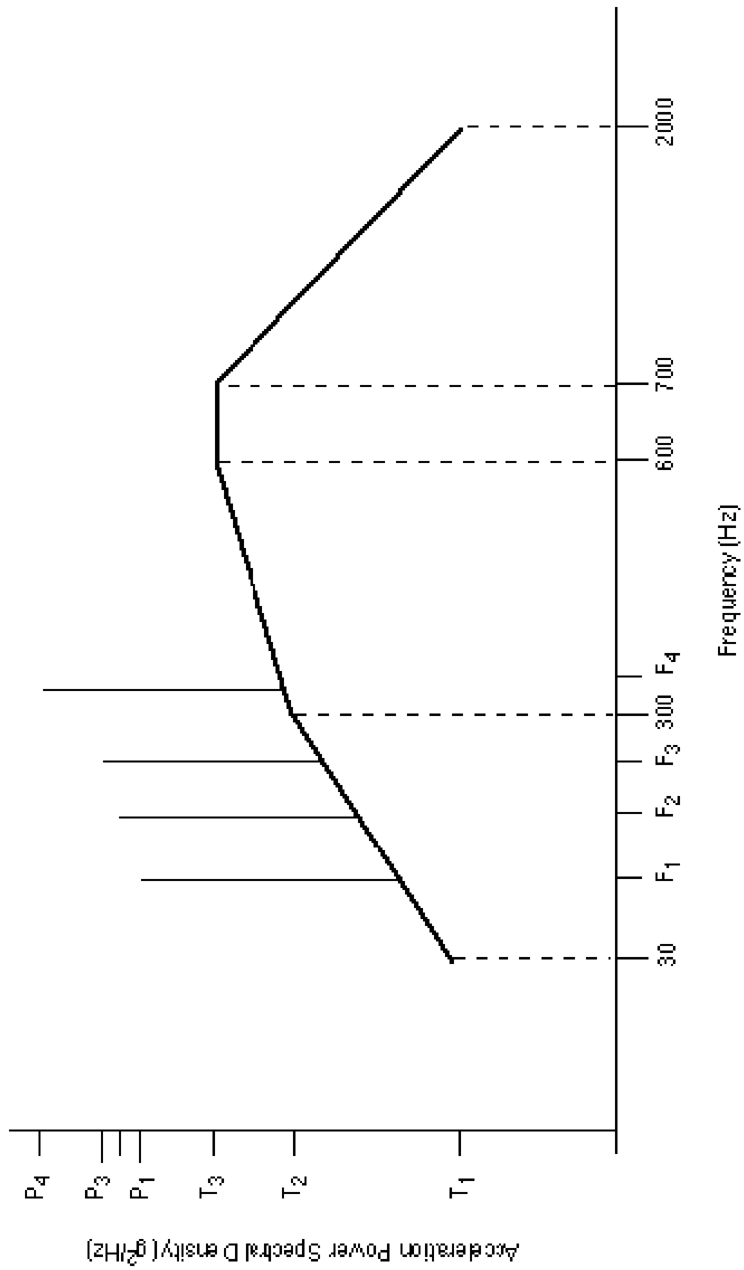


Figure D-1 Generalised gunfire induced vibration spectrum shape

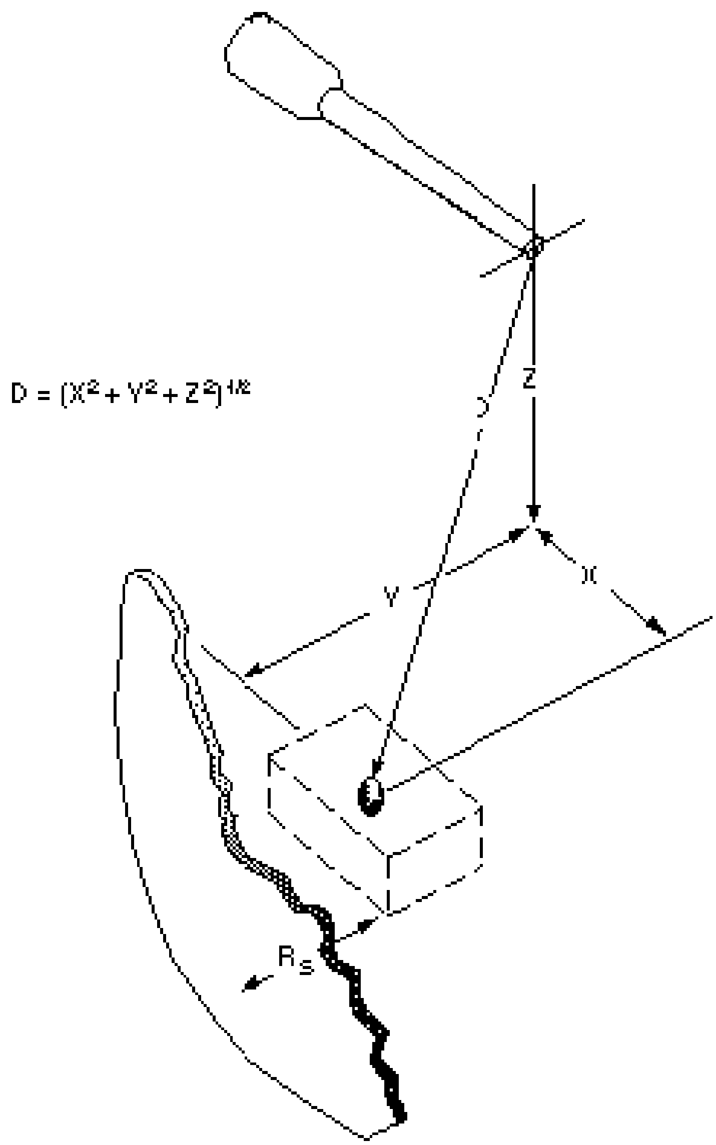


Figure D-2 The distance parameter (D) and the depth parameter (R_s)

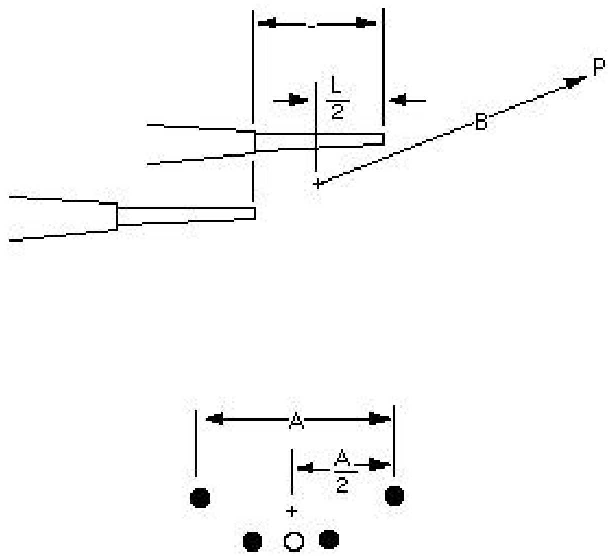


Figure D-3 Multiple guns, closely grouped

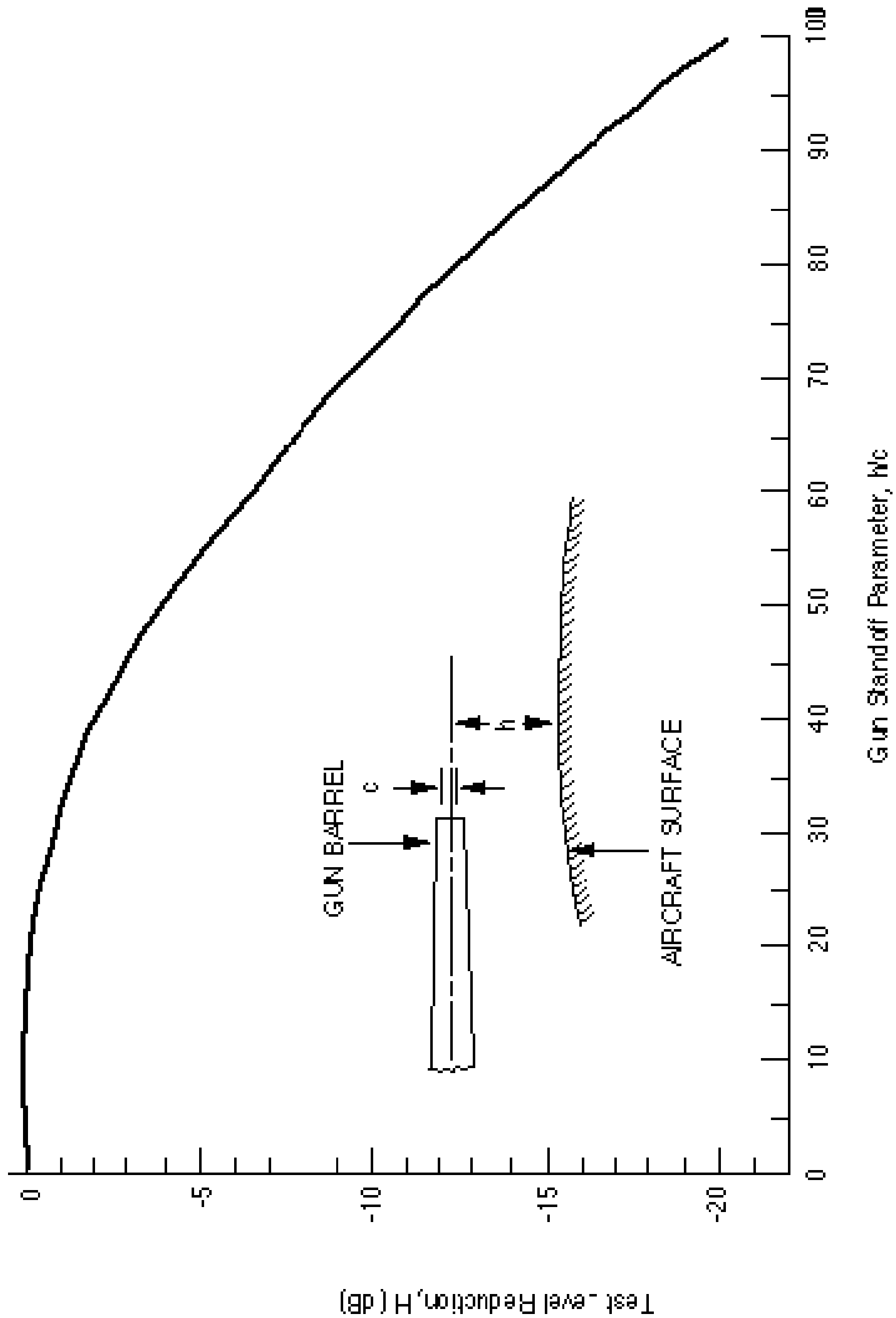


Figure D-4 Test level reduction due to gun standoff parameter

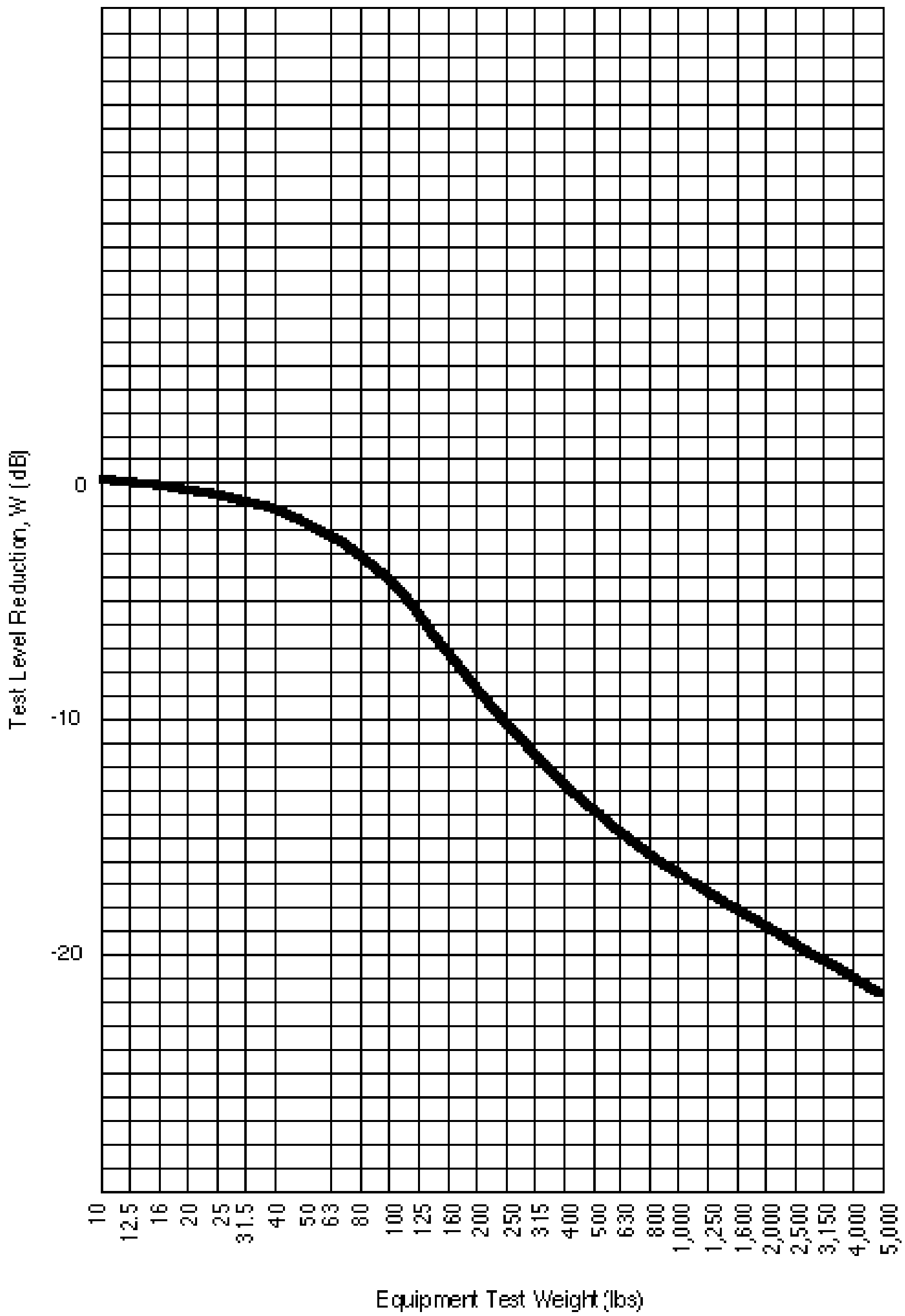


Figure D-5 Test level reduction due to materiel mass loading

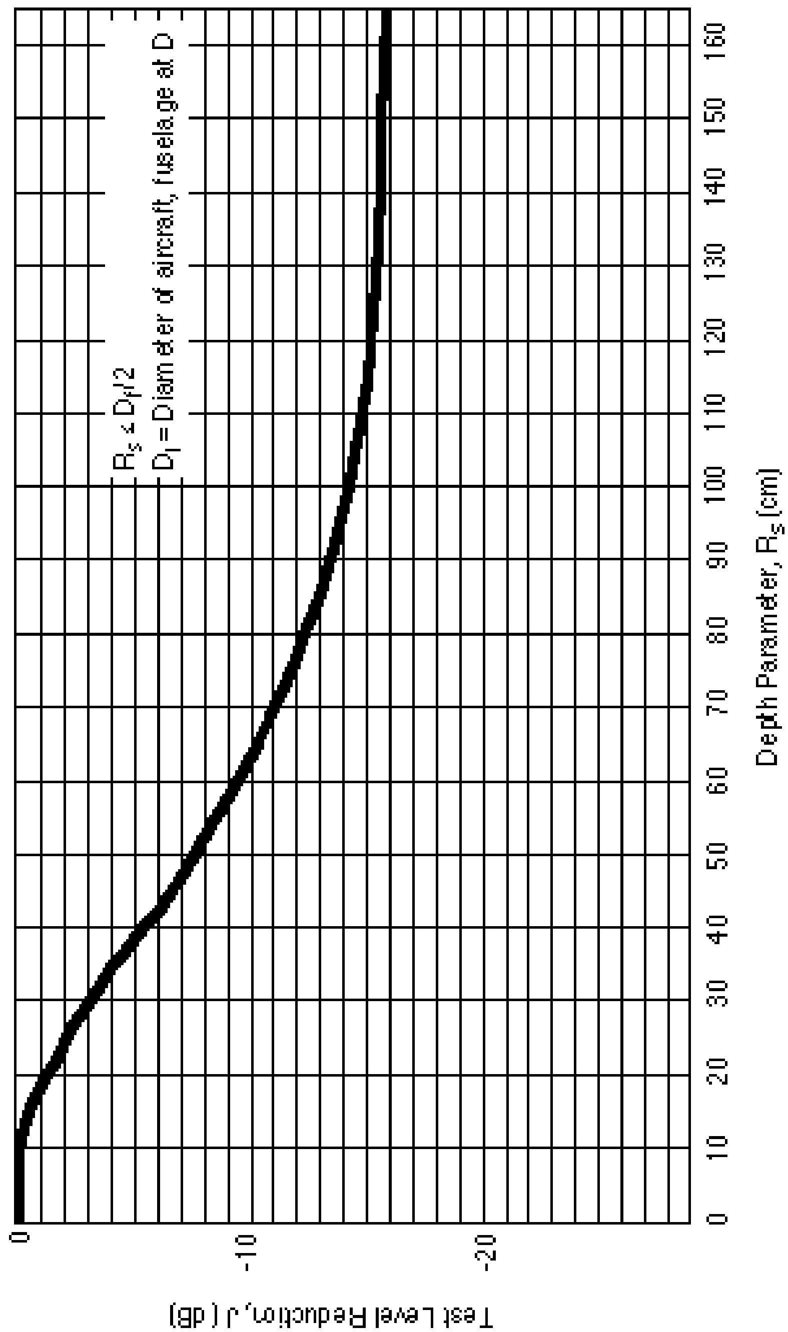


Figure D-6 Test level reduction due to depth parameter

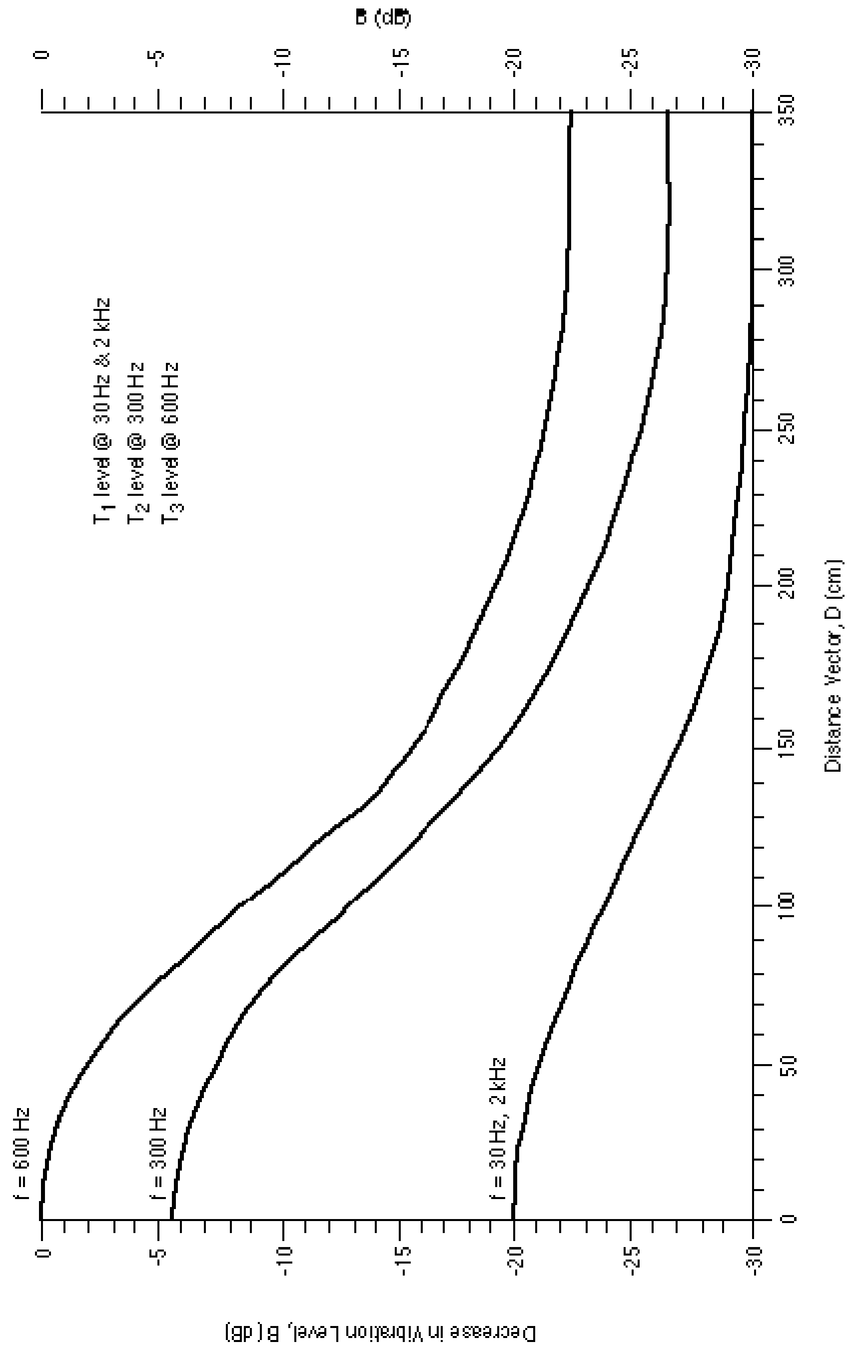


Figure D-7 Decrease in vibration level with vector distance from gun muzzle

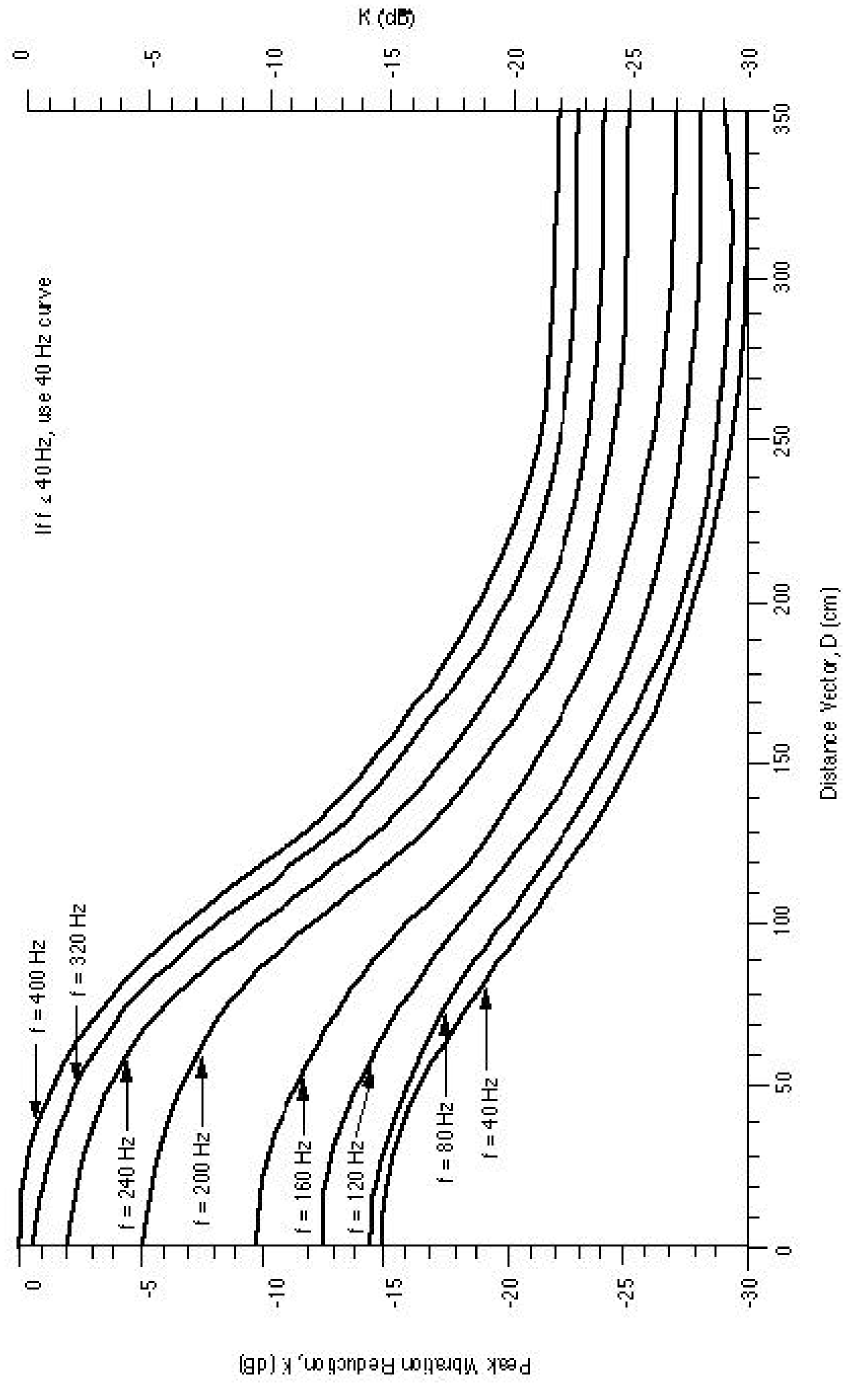


Figure D-8 Gunfire peak vibration reduction with distance

METHOD 406

LOOSE CARGO

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ANNEX B

ANNEX C

-

METHOD 406

LOOSE CARGO

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the effects of the transportation shock environment incurred by systems, subsystems and units (hereafter called materiel) during transportation as loose cargo in vehicles. In particular, this test method accommodates the unrestrained collision of materiel with the floor and sides of the cargo load bed and with other cargo.

1.2 Application

The test method is applicable where materiel is required to demonstrate its adequacy to resist the loose cargo environment without unacceptable degradation of its functional and/or structural performance. AECTP's 100 and 200 provide additional guidance on the selection of a test procedure for related vibration and shock environments during transportation.

1.3 Limitations

This method does not address vibrations as induced by secured cargo transportation or transportation of installed materiel, nor individual shocks or impacts inflicted during handling or accidents.

2. GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to the loose cargo environment.

(1) fatigue, cracking, rupture,

(2) deformation, specially of protruding parts,

(3) loosening of connections and seals,

(4) displacement of components,

(5) chafing of surfaces.

2.2 Use of Measured Data

The use of measured data is not applicable because the test control parameters cannot be adjusted sufficiently to match such data.

2.3 Sequence

In a test sequence, loose cargo tests will be scheduled in order to reflect as well as possible the projected service use profiles. However, if it is considered that this test would probably generate critical materiel failures then its position within the sequence could be changed.

2.4 Choice of Test Procedure

The choice of test procedures is governed by the test item configuration.

Two procedures are proposed. These two types differ from one another only in the installation of the test item.

These two types of test are for :

Procedure I : Equipment likely to slide (e.g., rectangular cross section items)

Procedure II : Equipment likely to roll (e.g., circular cross section items)

Circular synchronous motion is to be used for both types of tests.

2.5 Materiel Operation

Unless specified in the Test Instruction, the materiel is not operated during this test.

3. SEVERITIES

The test levels result from the rotational speed of the package tester table in the test facility and may be dependent on the individual apparatus and the test item configuration. The test time will be established using the projected service use profiles. Test severities are to be found in Annex A.

4. INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- the identification of the test item,
- the definition of the test item,
- the orientation of the test item in relation to the axis of throw of the test table,
- the operating checks: initial, final,
- the details required to perform the test,
- the monitor points on the test item (if any),
- the preconditioning time (if any)
- the definition of the test severity including test time,
- the indication of the failure criteria,
- the fencing configuration of the package tester,

4.2 If required

- tolerances, if different from para. 5.1.,

5. TEST CONDITIONS

5.1 Tolerances

The tolerance of the speed of rotation is +/- 2 rpm

5.2 Installation Conditions of Test Item

Procedure I. Using suitable fixturing as described in Annex B, the test item will be placed on the steel covered package tester bed (see Annex B). The wooden impact walls and sideboards shall be positioned so as to allow impacting on only one end wall (no rebounding) and to prevent rotation of the test item through 90 degrees about the vertical axis. Multiple test items will not be separated by sideboards. The test item will be positioned in its most likely shipping orientation. In the event the most likely shipping orientation cannot be determined, the test item will be placed on the bed with the longest axis of the test item parallel to the long axis of the table (throw axis).

Procedure II. Using suitable fixturing as described in Annex B, the test item will be placed on the steel covered bed of the package tester (see Annex B). The wooden impact walls and sideboards shall be placed so as to form a square test area (see Annex B for the formula to compute the area dimensions). The test item will be placed on the package tester in a random manner. Because part of the damage incurred during testing of these items is due to the items impacting each other, the number of test items should be greater than three.

5.3 Test Preparation

No test will be started on an area of the steel plate which is severely damaged or worn through.

5.3.1 Pre-conditioning

Unless otherwise specified, the test item should be stabilized to its initial conditions stipulated in the Test Instruction.

5.4 Initial and Final Checks

These checks include the controls and examinations stipulated in the Test Instruction.

5.5 Procedure

5.5.1 Procedure I

Step 1. Make the preconditioning checks in accordance with para. 5.3.1.

Step 2. Make the initial checks in accordance with para. 5.4.

Step 3. Place the test item on the bed of the package tester as specified in para. 5.2.

Step 4. Operate the table for the time specified in the Test Instructions. After half the total designated test time, the test shall be stopped, the test item shall be rotated 90 degrees about the test item vertical axis (using the same test area constraints described above), and the test continued.

Step 5. Make the final checks in accordance with para. 5.4.

Step 6. In all cases, record the information required

5.5.2 Procedure II

Step 1. Make the preconditioning checks in accordance with para. 5.3.1.

Step 2. Make the initial checks in accordance with para. 5.4.

Step 3. Place the test item on the bed of the package tester as specified in para. 5.2.

Step 4. Operate the table for the time specified in the Test Instructions. After half of the total designated test time the test shall be stopped, the test items once again placed in a random manner, and the test continued.

Step 5. Make the final checks in accordance with para. 5.4.

Step 6. In all cases, record the information required

6. FAILURE CRITERIA

The test item performance shall meet all appropriate specifications requirements during and following the loose cargo test.

ANNEX A

GUIDANCE FOR TEST SEVERITIES

The severity contained in this annex is based on measured data on items likely to slide and items likely to roll and is applicable to both Procedure I and Procedure II.

- Package tester rotation speed, circular synchronous motion: 300 rpm ± 2
- Test time: 20 minutes

This severity represents 240 km of loose cargo transport in tactical wheeled vehicles over rough terrain.

ANNEX B

TECHNICAL GUIDANCE

TEST FACILITY DESCRIPTION

Simulation of this environment requires use of a package tester which imparts a 25.4 mm (one inch) peak to peak circular motion to the table at a frequency of 5 Hz. This motion takes place in a vertical plane. The term multiple test items refers to identical test items and not a mixture of unrelated items.

(1) The test setup uses a package tester as depicted in figure 1. The fixturing required is as shown and will not secure the item to the bed of the package tester. The fence opposite the vertical impact wall is not intended as an impact surface, but is used to restrain the test item from leaving the tester. The distance to this restraining fence should be sufficient to prevent constant impact, but still prevent one or more of multiple test items from "walking" away from the others. The height of the test enclosure (sideboards, impact wall and restraining fence) should be at least 5 cm higher than the height of the test item to prevent unrealistic impacting of the test item on the top of the enclosure.

(2) The test bed of the package tester shall be covered with a cold rolled steel plate, 5 to 10 mm thick. The metal plate shall be secured with bolts, with the tops of the heads slightly below the surface. The bolts shall be at sufficient interval around the four edges and through the center area to prevent diaphragming of the steel plate.

(3) For the circular cross section items, the impact walls and sideboards shall be placed so as to form a square test area. The size of the test area is determined by a series of equations presented below. Derivation of these equations is presented in Annex C. SW and SB are chosen based on test item geometry to provide realistic impacting with the test bed impact walls and between test items. Typical value for both SW and SB is 25 mm. The following formula shall be used to determine the test area dimensions :

For values of the number of test items, N, > 3, the required slenderness ratio, R_r, is computed from equation 1 :

$$R_r = \frac{N\ L}{0.767\ L\,N^{1/2} - 2\,S_W - (N-1)S_B} \qquad \text{equation 1}$$

R_r = required slenderness ratio

L = length of the test item, cm

D = diameter of the test item, cm

N = number of test items

S_W = space between test item and wall, cm

S_B = space between each test item, cm

The test item actual slenderness ratio, R_a, is computed from:

$$R_a = L/D \qquad \text{equation 2}$$

and is independent of the number of test items, N.

If the actual test item slenderness ratio, R_a, is greater than the required ratio, R_r, computed in equation 1, then :

$$X = 0.767\ L\ N^{1/2} \qquad \text{equation 3}$$

X = length of each side of the square test area

If the actual test item slenderness ratio, R_a, is less than the required ratio, R_r, computed in equation 1, then :

$$X = N D + 2 S_W + (N-1) S_B \qquad \text{equation 4}$$

For values of N $\leq$ 3, the required slenderness ratio, R_r, is computed from equation 5 :

$$R_r = \frac{N\ L}{1.5\,L - 2\,S_W - (N-1)S_B} \qquad \text{equation 5}$$

If the actual test item slenderness ratio, R_a, is greater than the required ratio, R_r, computed in equation 5, then :

$$X \geq 1.5 L \qquad \text{equation 6}$$

Otherwise :

X is computed from equation 3.

Generally, if the actual slenderness ratio, L/D, is greater than 4, equations 3 or 6 (depending upon the number of test items) are applicable.

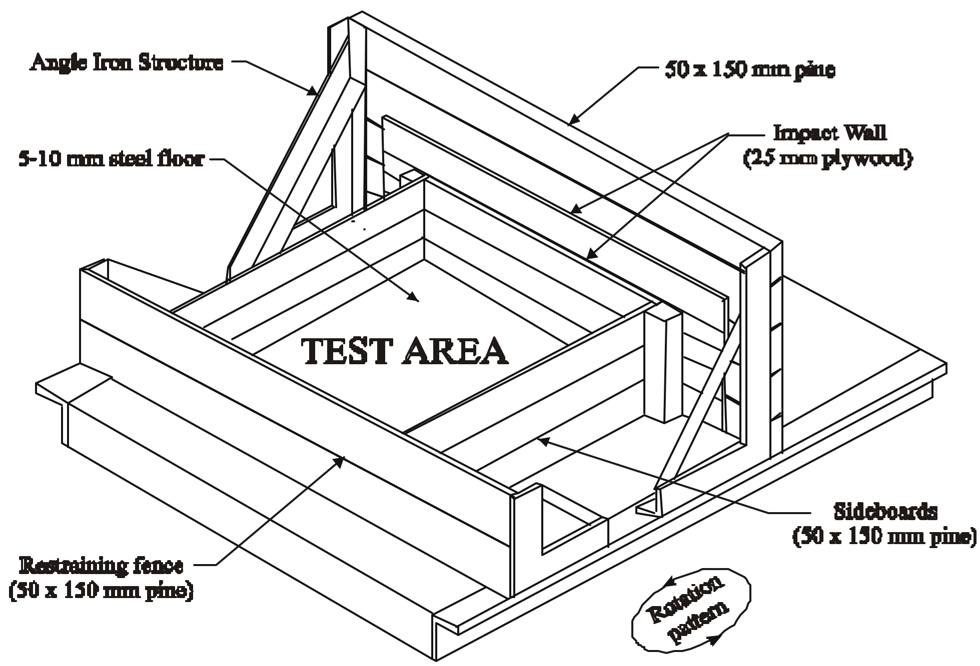

Figure 1. Typical Package Tester

ANNEX C

DERIVATION OF TEST AREA COMPUTATION EQUATIONS

Originally, the computation of the size of the test area for multiple (N > 3) circular cross section test items was computed from:

$$X = 0.767\ L\ N^{1/2} \qquad \text{equation 1}$$

X = length of each side of the square test area, cm

L = length of the test item, cm

N = number of test items

This was derived originally for testing slender items (e.g., rounds of ammunition) and is not applicable for items with a low slenderness ratio where the actual test item slenderness, R_a, is defined by:

$$R_a = L/D \qquad \text{equation 2}$$

R_a = actual test item slenderness ratio

L = length of the test item, cm

D = diameter of the test item, cm

The actual slenderness ratio is independent of the number of test items, N.

For any test item, the test area width may be defined as:

$$W = N\ D + 2S_w + (N-1)S_B \qquad \text{equation 3}$$

W = required width of square test area, cm

D = diameter of the test item, cm

N = number of test items

S_W = space between test item and wall, cm

S_B = space between each test item, cm

It is possible to compute a slenderness ratio required to determine if the test area is dependent upon the length or width of the test item by using the definition of R from equation 2 and calling this required value R_r.

$$R_r = L/D \qquad \text{equation 4}$$

Thus:

$$D = L/R_r \qquad \text{equation 5}$$

Substituting into equation 3:

$$W = (N\ L/R_r) + 2S_w + (N-1)S_B \qquad \text{equation 6}$$

Solving for R_r:

$$R_r = \frac{N\ L}{W - 2S_W - (N-1)S_B} \qquad \text{equation 7}$$

The diameter of the test item becomes the critical factor whenever the value W is equal to or greater than the value X. Since the value R_r is inversely proportional to W, it will reach a maximum value when W reaches a minimum value relative to X, or when W equals X. Combining equation 1 with equation 7:

$$R_r = \frac{N\ L}{0.767\ L N^{1/2} - 2S_W - (N-1)S_B} \qquad \text{equation 8}$$

If the test item has an actual slenderness ratio, R_a, greater than the required ratio, R_r, equation 1 is used to determine the test area. Otherwise, the test area is determined by equation 3.

The derivation can also be performed when the number of test items, N, $\leq$ 3. For this case, the original test area computation was based on:

$$X \geq 1.5L \qquad \text{equation 9}$$

The requirement for W may still be defined by equation 3. The critical value for R_r can be calculated by inserting the value of X from equation 9 as the value for W in equation 7. This yields:

$$R_r = \frac{N\ L}{1.5L - 2S_W - (N-1)S_B} \qquad \text{equation 10}$$

If the test item has an actual slenderness ratio, R_a, greater than the required ratio, R_r, equation 9 is used to determine the test area. Otherwise, the test area is determined by equation 3.

METHOD 407

MATERIEL TIEDOWN

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METHOD 407

MATERIEL TIEDOWN

1 SCOPE

1.1 Purpose

The purpose of this test method is to represent the loads incurred by materiel, including containers, during specified tiedown conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist during tiedown the specificied loads without unacceptable degradation of its structural and/or functional performance. It is particularly applicable to equipment having integral attachments such handles, eye bolts and shackles.

1.3 Limitations

This test does not address materiel performance while it is tied down.

2 GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel and its tiedown arrangements are subjected to tiedown loads.

(1) Failure of tiedown attachments.

(2) Failure or displacement of materiel structural or load spreading elements.

(3) Loosening of screws, rivets, etc.

2.2 Use of Measured Data

The use of measured data is not applicable.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on the materiel, they should be included in this test. Representative climatic data may be found in STANAG 2895 if measured data are not available.

2.4 Climatic Conditioning

This test should be conducted at the prevailing air temperature, unless it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature or humidity, then appropriate climatic conditions should be used.

3 SEVERITIES

This test should be performed in accordance with the severities of Annex A.

4 INFORMATION REQUIRED

The Test Instruction should include the following:

4.1 Compulsory

- the identification of the test item
- the definition of the test item
- the gross weight of the test item
- the type of test: development, qualification
- the visual or other examinations required, and the phase of the test in which they are to be conducted
- the definition of the failure criteria
- the loading and environmental conditions at which testing is to be carried out
- tolerances

4.2 If Required

- any permitted deviations from this test method

5 TEST CONDITIONS

5.1 Preparation for Test

5.1.1 Loading Devices

Each loading device used for these tests should have suitable safe working load carrying capacity.

5.1.2 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilized, whichever is the shorter period. (See AECTP 300, Method 301).

5.1.3 Checks

Initial, during testing and final checks are to be conducted as specified in the Test Instruction.

5.2 Procedure

Step 1. Unless otherwise specified in the Test Instruction, position the test item on a hard and level test surface and secure it sufficiently to prevent movement.

Step 2. Apply the test load(s) in the direction(s) specified in the Test Instruction. The test load(s) should be applied statically to each attachment, one at a time. (If the test load(s) are derived from Annex A, the load(s) should be applied orthogonally, as indicated, to each attachment, one at a time).

Step 3. Apply the load(s) for the time period specified.

6 FAILURE CRITERIA

Unless otherwise specified in the Test Instruction the tiedown attachments are expected to survive the test without degradation and should be fit-for-purpose on completion of the test.

ANNEX A

INITIAL TEST SEVERITIES

DIRECTION	LOAD	MINIMUM TEST DURATION (Minutes)	CLIMATIC CONDITIONS
Forward/aft (Longitudinal axis of equipment)	$\frac{4 \text{ x } MSW *}{N}$	5	Prevailing Site Conditions
Downward	$\frac{2 \text{ x } MSW}{N}$	5	
Lateral (in each direction)	$\frac{1.5 \text{ x } MSW}{N}$	5	

Reference : developed from MIL -STD-209G

*MSW = Maximum weight of item (including payload in the case of container test).

N = Number of attachments effectively resisting motion in that axis.

METHOD 408

LARGE ASSEMBLY TRANSPORT

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METHOD 408

LARGE ASSEMBLY TRANSPORT

1. SCOPE

1.1 Purpose

The purpose of this method is to replicate the vibration and shock environment incurred by large assemblies of materiel installed or transported in wheeled or tracked vehicles. In this test method, the specified vehicle type is used to provide the mechanical excitation to the installed or transported assembly.

1.2 Application

This test is applicable to:

- materiel comprising a large assembly,
- materiel forming a high proportion of the vehicle gross mass,
- materiel forming an integral part of the vehicle.

which is required to demonstrate its adequacy to resist the specified ground mobility conditions without unacceptable degradation of its functional and/or structural performance.

This test method is also applicable where a laboratory test such Test Method 401 - Vibration, or Test Method 406 - Loose Cargo, may not be practicable or cost effective.

AECTPs 100 and 200 provide additional guidance on the selection of test procedure for ground mobility conditions.

1.3 Limitations

None specified.

2. GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to ground mobility conditions.

(1) Wire chafing.

(2) Loosening of fasteners.

(3) Intermittent electrical contacts.

(4) Mutual contact and short circuiting of electrical components.

(5) Seal deformation.

(6) Structural and component fatigue.

(7) Optical misalignment.

(8) Loosening of components.

(9) Excessive electrical noise.

2.2 Use of Measured data

In principle the use of measured data is not relevant to this test method. However, measured data is often acquired during this test to check that vibration and shock specifications for the materiel subassemblies are realistic.

2.3 Sequence

The test will comprise several parts involving different road surfaces, distances and vehicle speeds, and in some cases different vehicles. The order of application of each part should be considered and made compatible with the Service Life Environment Profile.

2.4 Test Facility

When setting up the test, consideration must be given to the test surfaces available at the particular test location selected to undertake the test. Also, the selection of the test surfaces and related test distances must be appropriate for the specified type of vehicles and their anticipated use.

2.5 Strapping Arrangements

It is important to reproduce during the test the more adverse arrangements which could arise in normal use. For example, during transportation excessive tightening of webbing straps could prevent movement of the test item(s) during the test and thereby limit the damaging effects; whereas relaxation of strap tension during service use could produce repeated shock conditions.

2.6 Large Assembly Installation

The test item should be installed in the vehicle in its design configuration. If the assembly is to be contained within a shelter, or if other units are attached to the materiel assembly in its in-service configuration, then these items should also be installed in their design configuration.

3. SEVERITIES

There are no preferred severity levels. Military vehicles fall into the following broad groups:

(1) Medium mobility wheeled land vehicles spending a high proportion of their life on normal paved roads.

(2) High mobility wheeled land vehicles spending time on both raods and cross country conditions.

(3) Tracked vehicles

Distances and speeds, together with any restrictions on weather conditions, shall be formulated for each vehicle type and shall cover all relevant surface types, such as smooth roads, rough roads and cross country.

All such selections and formulations for the test shall be agreed with the authority responsible for compliance with the environmental requirements.

A typical set of test conditions is shown in Annex A.

4. INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- The identification of the item(s) to be tested,
- The type of test: development, qualification, etc,
- if operating checks are to be performed and when,
- the type(s) of vehicle(s) to be tested and the associated load state(s),
- the test conditions for each vehicle and the associated tolerances for distance and vehicle speed,
- the configuration of the materiel during the test,
- the climatic conditions under which the test is to be conducted if other than ambient,
- other relevant data required to perform the test and operating checks,
- a statement of the failure criteria.

4.2 If Required

(None identified)

5. TEST CONDITIONS

5.1 Installation Conditions of Test Item

The test item shall be mounted in the vehicle as stated in the Test Instruction.

5.2 Procedure

Step 1. Examine the test item and carry out any required performance checks.

Step 2. The vehicle containing the test item shall be subjected to the specified test conditions.

Step 3. Any required performance checks shall be undertaken as specified.

Step 4. Test item shall be examined as specified for any detrimental effects.

Step 5. In all cases, record the information required.

6. FAILURE CRITERIA

The performance of the test item shall meet all appropriate specification requirements during and following the application of the test conditions.

ANNEX A

TYPICAL SET OF TEST CONDITIONS

The vehicle containing the test item shall be driven five times over the following test surfaces at the specified speeds:

(1)	Coarse washboard (150 mm waves spaced 2 m apart)	8 km/h
(2)	Belgian block	24km/h
(3)	Radial washboard (50 mm to 100 mm waves)	24 km/h
(4)	50 mm washboard	16 km/h
(5)	75 mm spaced bump	32 km/h

The speeds used for the test will be as specified unless these exceed safe driving conditions, in which case the maximum safe operating speed will be agreed with the authority responsible for compliance with the environmental requirements.

METHOD 409

MATERIEL LIFTING

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ANNEX A

INITIAL TEST SEVERITIES

METHOD 409

MATERIEL LIFTING

1. SCOPE

1.1 Purpose

The purpose of this test method is to represent the loads incurred by materiel, including containers, during specified lifting conditions.

1.2 Application

This test is applicable when materiel is required to demonstrate its adequacy to resist during lifting the specified loads without unacceptable degradation of its structural and/or functional performance. It is particulary applicable to lifting attachments on materiel such as handles, eye bolts and their attachments to the materiel, fork lift attachments, provision for grabs, as well as equipment which is not provided with any specific lifting device.

1.3 Limitations

This test method is not applicable to snatch loading conditions and is only applicable to individual items of materiel. When several items are to be handled as a single load, the Test Instruction must state the test requirements.

2. GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel and its lifting arrangements are subjected to lifting loads.

(1) Failure of lifting attachments

(2) Failure or displacement of local structural or load spreading elements.

(3) Loosening of screws, rivets, etc.

(4) Unsecure furniture and fittings.

(5) Deterioration of climatic protection.

(6) Damage to protective coatings.

2.2 Use of Measured Data

The use of measured data is not applicable.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on the materiel they should be included in this test. Representative climatic data may be found in STANAG 2895 if measured data are not available.

2.4 Climatic Conditioning

This test should, wherever practical, be conducted in a chamber with the test item stabilised at the required conditions. If size limitations or safety hazards prevent this, the stabilised test item should be removed from the chamber, the test conducted as quickly as possible and the room ambient conditions recorded. Reconditioning of the test item may be required if the temperature of the test item exceeds the tolerances in the Test Instructions.

2.5 Choice of Test Procedures

The choice of test procedures is governed by the configuration of the materiel lifting arrangements. Five procedures are presented as follows:-

Procedure 1: Materiel fitted with handles

Procedure 2: Materiel fitted with lifting attachments

Procedure 3: Materiel fitted with fork lift facilities

Procedure 4: Materiel provided for the use of grabs

Procedure 5: Materiel with no lifting devices

3. SEVERITIES

This test should be performed in accordance with the severities of Annex A, which presents values that have been used arbitrarily in the past. When it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature or humidity, appropriate climatic conditions should be used.

4. INFORMATION REQUIRED

4.1 Compulsory

- the identification of the test item,
- the definition of the test item,
- the gross weight of the test item,
- the type of test: development, qualification,
- the visual or other examinations required, and the phase of the test in which they are to be conducted,
- the definition of the failure criteria,
- the loading of environmental conditions at which testing is to be carried out,
- the tolerances.

4.2 If Required

- any permitted deviations from this test method.

5. TEST CONDITIONS

5.1 Preparation for Test

5.1.1 Lifting Devices

Each lifting device used for these tests should have suitable safe working load carrying capacity.

5.1.2 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilised, whichever is the shorter period.(See AECTP 300, Method 301,Paragraph 9)

5.1.3 Initial, during testing and final checks

They are to be conducted as specified in the Test Instruction.

5.2 Procedures

5.2.1 Procedure 1 - Materiel Fitted with Handles

Step 1. Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2. Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.

Step 3. Lift the test item and freely suspend it from each handle in turn for the period specified in the Test Instruction.

5.2.2 Procedure 2 - Materiel Fitted with Lifting Attachments

Step 1. Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2. Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.

Step 3. Lift the test item and fully suspend it from each lifting attachment in turn for a period specified in the test instructions.

Step 4. Lift the test item and load using slings attached to the lifting points and maintain the freely suspended test item in this position for a period as specified in the Test Instruction. The angles between the legs of a two legged sling and the diagonal opposite legs of a four legged sling should not be more than 90? and not less than 60?.The test load shall not interfere with the attachment and alignment of the slings.

5.2.3 Procedure 3 - Materiel Fitted with Fork Lifting Facilities

Step 1. Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2. Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.

Step 3. Lift the test item clear of the ground with a fork lift truck with the forks extended to at least two thirds of the underside dimensions of the base of the specimen across which the forks are carrying out the lift. Maintain this position for the period as specified in the Test Instruction.

5.2.4 Procedure 4 - Materiel Providing for the Use of Grabs

Step 1. Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2. Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.

Step 3. Lift the test item with grabs applied at the designated grab points and suspend the test item clear of the ground for the period stipulated in the Test Instruction.

5.2.5 Procedure 5 - Materiel with No Lifting Devices

Step 1. Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2. Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.

Step 3. Lift the test item by two slings positioned at approximately one sixth of the length of the container from each end and held clear of the ground for the period stipulated in the Test Instruction. The angle between the diagonally opposite legs of the slings should not be more than 90? and not less than 60?.

6. FAILURE CRITERIA

The test item performance should meet all appropriate specification requirements during and following the application of the test loading and environmental conditions.

Unless otherwise specified in the Test Instruction lifting arrangements are expected to survive the test without degradation and the materiel should remain safe and fit-for-purpose on completion of the test.

ANNEX A

INITIAL TEST SEVERITIES

Procedure	Load Factors	Test Duration Minutes	Climatic Conditions
1	3	5	Prevailing Test Site Conditions
2	2	5	
3	1.25	5	
4	2	5	
5	3	5	

The test load is the gross weight of the materiel (materiel weight plus weight of contents in the case of container test) multiplied by the load factor

METHOD 410

MATERIEL STACKING

TABLE OF CONTENTS

ANNEX A

INITIAL TEST SEVERITIES

METHOD 410

MATERIEL STACKING

1 SCOPE

1.1 Purpose

The purpose of this test method is to represent the compression loads incurred by materiel, including containers, during specified stacking conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist during stacking the specified compression loads without unacceptable degradation of the structural and/or functional performance. It is particulary applicable to materiel structural elements which may be subjected to the compressive loads applied to lower materiel in a stack of identical materiel. It is also applicable to materiel that may be subjected to side compressive loads that are applied whilst materiel is being lifted by a net.

1.3 Limitations

This test is not applicable for the simulation of rapidly applied loads such as drop conditions, that could arise during the handling and stacking of materiel.

2 GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is subjected to compressive loads arising from stacking.

(1) Failure or displacement of local structural or load spreading elements.

(2) Loosening of screws, rivets, fastenings, etc.

(3) Unsecure furniture and fittings.

(4) Deterioration of climatic protection.

(5) Damage to protective coatings.

It is important to recognise for some types of materiel that they can, over prolonged periods, buckle or partially collapse when stored in conditions of high relative humidity or when wet from exposure to the weather.

2.2 Use of Measured Data

The use of measured data is not applicable.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on materiel they should be included in this test. Representative climatic data may be found in STANAG 2895 if measured data are not available.

2.4 Climatic Conditioning

This test should, wherever practical, be conducted in a chamber with the test item stabilised at the required conditions. If size limitations or safety hazards prevent this, the stabilised test item should be removed from the chamber, the test conducted as quickly as possible and the room ambient conditions recorded. Re-conditioning of the test item may be required if the temperature of the Test Item exceeds the tolerances in the Test Instructions.

2.5 Load Distribution

Where it is important to simulate the load distribution at the interface between the bottom and the next lowest materiel a minimum of two test items should be used for the test.

Where materiel is stacked as palletized loads, so that the lowest materiel is supported by a pallet, this pallet may need to be included (or the effect simulated) in the test.

Where uneven compressive loads could arise from stacking materiel or uneven surfaces during shipping, then these conditions should be simulated in the test.

When staggered stacking could arise during in-service conditions then such arrangements should be simulated in the test.

Where an equipment can be expected to be stacked in more than one orientation, then all materiel sides relevant to these orientations should be subjected to this stacking test.

3 SEVERITIES

This test should be normally performed in accordance with the severities of Annex A When it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature or humidity, appropriate climatic conditions should be used.

4 INFORMATION REQUIRED

4.1 Compulsory

- the identification of the test item,
- the definition of the test item,
- the gross weight of the test item,
- the type of test: development, qualification,
- the visual or other examinations required, and the phase of the test in which they are to be conducted,
- the loading and environmental conditions at which testing is to be carried out and the associated durations,

- the test item faces to which the test is to be applied,
- the definition of the failure criteria,
- tolerances,

4.2 If Required

- the test surface, if other than a hard level surface
- the load distributions, if adverse conditions need to be tested
- any permitted deviations from this test method

5 TEST CONDITIONS

5.1 Preparation for Test

5.1.1 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilised, which ever is the shortest period (AECTP 300, Method 301, Paragraph 9).

5.1.2 Checks

Initial, during testing and final checks are to be conducted as specified in the Test Instruction.

5.2 Procedures

5.2.1 Procedure 1 - Vertical Loading (Simulating Stacking Loadings)

Step 1. Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2. Conduct the appropriate compression test on the uppermost surface of the test item using the load and duration specified in the Test Instruction.

Step 3. If testing outside the temperature conditioning facility, re-stabilise the test item at the required temperature.

Step 4. Repeat the test of Step 2 for the next appropriate test item orientation.

Step 5. Repeat Steps 3 and 4 for all remaining orientations.

5.2.2 Procedure 2 -Side or End Loading (Simulating Net Loadings)

Step 1. Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2. Subject the side or end faces of the test item to the test load and test duration specified in the Test Instruction. A suitable horizontal loading device should be used if the test item is sensitive to equipment orientation or to gravity effects.

This test procedure is not applicable to equipment which has a gross mass of 120kg or more, or a volume of $0.28m^3$ or more.

6 FAILURE CRITERIA

The test item performance should meet all appropriate specification requirements during and following the application of the test loading and environmental conditions.

Unless otherwise specified in the Test Instruction the equipment is expected to survive the test without degradation and the equipment should remain safe and fit-for-purpose on completion of the test.

ANNEX A

INITIAL TEST SEVERITIES

Load

A static load should be applied equivalent to that which would be produced by stacking on the materiela number of similar materiel to a total height not exceeding 2m for containers up to 15kg gross mass, or 6m for equipment over 15kg gross mass.

Duration

The load should be applied for a period of 8 days.

Climatic Conditions

Prevailing test site conditions.

METHOD 411

MATERIEL BENDING

TABLE OF CONTENTS

ANNEX A

INITIAL TEST SEVERITIES

METHOD 411

MATERIEL BENDING

1. SCOPE

1.1 Purpose

The purpose of this test is to represent the bending loads incurred by materiel, including containers, during specified transit conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist during transit the spcecified bending loads without unacceptable degradation of its structural and/or functional performance. It is particulary applicable to materiel structural elements which may be subjected to the bending loads caused by own mass and/or by top loading with other materiel of different mass and proportions.

1.3 Limitations

The use of this test is normally limited only to materiel whose length exceeds four times the smallest cross sectional dimension.

2. GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is subjected to bending loads.

(1) Failure or displacement of structural elements.

(2) Loosening of screws, rivets, fastenings, etc.

(3) Unsecure furniture and fittings.

(4) Deterioration of climatic protection.

(5) Damage to protective coatings.

It is important to recognise for some types of materiel that they can, over prolonged periods, buckle or partially collapse when stored in conditions of high relative humidity or from wet when exposure to the weather.

2.2 Use of Measured Data

The use of measured is not applicable.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on the materiel, they should be included in this test. Representative climatic data may be found in STANAG 2895 if measured data are not available.

2.4 Climatic Conditioning

This test should, wherever practical, be conducted in a chamber with the test item stabilised at the required conditions. If size limitations or safety hazards prevent this, the stabilised test item should be removed from the chamber, the test conducted as quickly as possible and the room ambient conditions recorded. Re-conditioning of the test item may be required if the temperature of the Test Item exceeds the tolerances in the Test Instructions.

2.5 Load Distribution

Where the equipment normally rests on supports and/or adopts a particular attitude during transit then these conditions should be simulated in the test.

The test item should be supported at each end and a static load applied over a centre span area of the test item. The centre span area shall extend the full width of the test item and be equal to the cross sectional area of the test item. The ends of the test item should be supported over an area equal to half the centre span area.

3. SEVERITIES

This test should be normally performed in accordance with the severities of Annex A. When it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature, appropriate climatic conditions should be used.

4. INFORMATION REQUIRED

The Test Instruction should include the following:

4.1 Compulsory

- the identification of the test item,
- the definition of the test item,
- the gross weight of the test item,
- the type of test: development, qualification,
- the visual or other examinations required, and the phase of the test in which they are to be conducted,
- the loading and environmental conditions at which testing is to be carried out and the associated durations,
- the equipment faces to which the test is to be applied,
- the definition of the failure criteria,
- the tolerances.

4.2 If Required

- the test support, if other than hard and level supports,
- the load distributions, if adverse conditions need to be tested,
- any permitted deviations from this test method.

5. TEST CONDITIONS

5.1 Preparation for Test

5.1.1 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilised, whichever is the shorter period). (See AECTP 300, Method 301).

5.1.2 Checks

Initial, during testing and final checks are to be conducted as specified in the Test Instruction.

5.2 Procedure

Step 1. Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface. The geometry of the supports is defined in par. 2.5.

Step 2. Apply the test load (distributed as described in paragraph 2.5) to the upper surface of the test item using the load and duration specified in the Test Instruction.

Step 3. If testing outside the temperature conditioning facility, re-stabilise the test item at the required temperature.

Step 4. Repeat the test of Step 2 for the next appropriate test item orientation.

Step 5. Repeat Steps 3 and 4 for all remaining orientations.

6. FAILURE CRITERIA

The test item performance should meet all appropriate specification requirements during and following the application of the test loading and environmental conditions.

Unless otherwise specified in the Test Instruction the materiel structure is expected to survive the test without degradation and the materiel should remain safe and fit-for-purpose on completion of the test.

ANNEX A

INITIAL TEST SEVERITIES

Load

A static load of three times the gross weight of the materiel should be applied over the centre span of the materiel (see paragraph 2.5 for load distribution).

Duration

The load should be applied for a period of not less than five minutes.

Climatic Conditions

Prevailing test site conditions.

METHOD 412

MATERIEL RACKING

TABLE OF CONTENTS

METHOD 412

MATERIEL RACKING

1. SCOPE

1.1 Purpose

The purpose of this test method is to represent the existing loads incurred by materiel, including containers, during specified racking conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist during racking the specified twisting loads without unacceptable degradation of its structural and/or functional performance.

1.3 Limitations

The use of this test is normally limited only to materiel in excess of 225kg gross mass.

2. GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is subjected to twisting loads arising from racking.

(1) Failure or displacement of structural elements.

(2) Loosening of screws, rivets, fastenings, etc.

(3) Unsecure furniture and fittings.

(4) Deterioration of climatic protection.

(5) Damage to protective coatings.

It is important to recognise for some types of materiel that they can, over prolonged periods, buckle or partially collapse when stored in conditions of high relative humidity or from wet when exposure to the weather.

2.2 Use of Measured Data

The use of measured data is not applicable.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on the materiel they should be included in this test. Representative climatic data may be found in STANAG 2895 if measured data are not available.

2.4 Climatic Conditioning

This test should, wherever practical, be conducted in a chamber with the test item stabilised at the required conditions. If size limitations or safety hazards prevent this, the stabilised test item should be removed from the chamber, the test conducted as quickly as possible and the room ambient conditions recorded. Re-conditioning of the temperature of the Test Item exceeds the tolerances in the Test Instructions.

2.5 Load Distribution

Where the equipment normally rests on supports and/or adopts a particular attitude during transit then these conditions should be simulated in the test.

3. SEVERITIES

This test should be normally performed in accordance with the severities of Annex A. When it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature, appropriate climatic conditions should be used.

4. INFORMATION REQUIRED

4.1 Compulsory

- the identification of the test item,
- the definition of the test item,
- the gross weight of the test item,
- the type of test: development, qualification,
- the visual or other examinations required, and the phase of the test in which they are to be conducted,
- the loading and environmental conditions at which testing is to be carried out and the associated durations,
- the face on which the test is to be carried out if there is no designated equipment base,
- the definition of the failure criteria,
- the tolerances.

4.2 If Required

- the test supports, if other than hard and level supports;
- the load distributions, if adverse conditions need to be tested;
- any permitted deviations from this test method.

5. TEST CONDITIONS

5.1 Preparation for Test

5.1.1 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilised, whichever is the shorter period. (See AECTP 300, Method 301).

5.1.2 Checks

Initial, during testing and final checks are to be conducted as specified in the Test Instruction.

5.2 Procedure

Step 1. Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2. Apply the test load (in accordance with the loading conditions defined in Annex A) as specified in the Test Instruction.

Step 3. If testing outside the temperature conditioning facility, re-stabilise the test item at the required temperature.

Step 4. Repeat the test of step 2 for the next appropriate test item orientation.

Step 5. Repeat steps 3 and 4 for all remaining orientations.

6. FAILURE CRITERIA

The test item performance should meet all appropriate specification requirements during and following the application of the test loading and environmental conditions.

Unless otherwise specified in the Test Instruction the materielequipment structure is expected to survive the test without degradation and the materiel should remain safe and fit-for-purpose on completion of the test.

ANNEX A

INITIAL TEST SEVERITIES

Loading Conditions and Duration

With the test item standing upon ts face on a hard, level surface, a base corner shall be lifted and supported at a height of 30 mm for a period of not less than 5 minutes.

The test item shall then be lowered and the operation repeated on the diagonally opposite corner.

The two remaining corners shall then be similarly treated.

Climatic Conditions

Prevailing test site conditions.

METHOD 413

ACOUSTIC NOISE COMBINED WITH TEMPERATURE AND VIBRATION

TABLE OF CONTENTS

ANNEX A

DERIVATION OF TEST PARAMETERS

ANNEX B

FACILITY REQUIREMENTS

METHOD 413

ACOUSTIC NOISE COMBINED WITH TEMPERATURE AND VIBRATION

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the environment induced in the internal equipment (hereafter called materiel) of stores and missiles when carried externally on high performance aircraft during the specified operational conditions.

To achieve a close simulation, this test method combines acoustic noise excitation with mechanical vibration and ducted air conditioning to produce the required mechanical and thermal responses in the internal units of the test item. The test method is also capable of reproducing the changes in the vibration and temperature responses that arise during specific aircraft mission profiles.

1.2 Application

This test is applicable where materiel is required to demonstrate its adequacy to resist the specified environment without unacceptable degradation of its functional and/or structural performance.

The principles of this test method may also be applicable to the simulation of other vibration environments, such as those induced during missile flight conditions.

AECTPs 100 and 200 provide additional guidance on the selection of a test procedure for a specific environment.

1.3 Limitations

Where this test is used for the simulation of aerodynamic turbulence, it is not necessarily suitable for proving thin shell structures interfacing directly with the acoustic noise.

2. GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel are exposed to this combined environment.

(l) Wire chafing

(2) Component fatigue

(3) Component connecting wire fracture

(4) Cracking of printed circuit boards

(5) Failure of waveguide components

(6) High cycle fatigue failure of small panel areas

(7) High cycle fatigue failure of small structural elements

(8) Optical misalignment

(9) Loosening of small particles that may become lodged in circuits and mechanisms

(10) Excessive electrical noise

2.2 Use of Measured and Related Data

Where practicable, field data should be used to develop test levels. It is particularly important to use field data where a precise simulation is the goal. The parameters and profiles are influenced by store type, aircraft installation, aircraft performance and mission conditions. Their derivation is given in Annex A. When flight measured data are not available, sufficient information is presented in Annex A to determine test profiles and levels.

2.3 Sequence

This test is designed for the simulation of the primary environmental effects that are induced in complete assembled stores during external carriage on fixed wing aircraft. However, should a test item need to be exposed to any additional environmental tests, then the order of application of the tests should be compatible with the Life Cycle Environmental Profile.

2.4 Rationale for Procedure and Parameters

2.4.1 Test Rationale

In particular this test is designed to reproduce the main responses measured in flight at the internal units of complete assembled stores and to provide a realistic simulation of relevant flight mission conditions through the use of acoustic noise, vibration and temperature conditioning.

The materiel arrangement for this test is shown, diagrammatically, in Figure 1. Acoustic noise will be applied using the acoustic field of a reverberation chamber while low frequency excitation of the store will be induced by a mechanical vibrator. This broadly represents the operational environment in that low frequency excitation, below about 100 Hertz, normally results from mechanical input through the attachment points. At higher frequencies the major in-service excitation source results from aerodynamic excitation over the total wetted surface of the store and this is simulated in the test condition by the acoustic noise field. A more detailed description of the facility requirements is given in Annex B

2.4.2 Test Parameters

All environmental parameters are controlled from the responses of the test item. Thus the vibration and acoustic noise excitation should be controlled to give the required internal unit vibration responses. Temperature control should normally be achieved at an external thin skin section as the internal component temperatures will be significantly affected by time constants and power dissipation during power on periods.

Therefore, the parameters required to fully define the test conditions are:

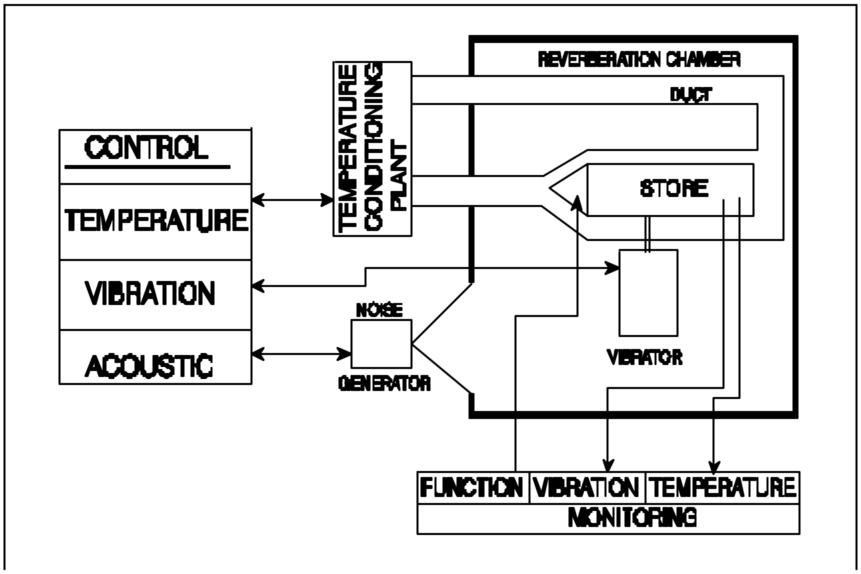

Figure 1 - Typical Facility Layout

a) The temperature profile in terms of constant temperatures, rates of change of temperature during transition periods and time intervals for each element of the mission.

b) The vibration response in terms of spectrum, rms acceleration level and location(s), and the durations for each element of the mission.

2.4.3 Precursor Trials

Control of the test conditions is derived from store responses. Therefore, a representative store should be made available for precursor trials in order to establish the required excitation conditions. It may be necessary to control the vibration response of the store from external locations such as at strong points of the structure. In this case it is required that the external control characteristics be established after setting up the reference condition at the internal location(s). The precursor trial should be carried out in accordance with paragraph 5.6.1.

2.5 Materiel Operation

When specified, during in-service simulations, the test item should be functioning and its performance should be measured, and noted.

3. SEVERITIES

Test levels and durations should be established using data acquired directly from the project environmental data gathering programme, from the International Standard Atmosphere (ISA) tables or equivalent, other appropriate flight measured data, or critical design conditions derived from projected Life Cycle Environmental Profiles. These test parameters should be derived in accordance with the procedure given in Annex A.

4. INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- the identification of the test item.
- the definition of the test item.
- the type of test: development, reliability, etc.
- the times at which the test item is to be operating during the test.
- the operating checks required: initial, during the test final.
- the details required to perform the test including the method of installation of the test item.
- the monitor and control points or a procedure to select these points.
- the indication of the failure criteria.
- The initial conditions, from methods 302 and 305 or from measured data
- the initial conditions as derived from Methods 302/305 or from measured data.

4.2 If required

- the effect of gravity and the consequent precautions.
- the tolerances, if different from paragraph 5.1

5. TEST CONDITIONS

5.1 Tolerances

As the test may be controlled on vibration, acoustic, temperature and duration parameters, tolerances should be specified for all relevant parameters.

If tolerances are not met, the differences observed shall be noted in the test report.

5.1.1 Vibration

For broad band random elements of the test the tolerances should be in accordance with those in Method 401 Vibration.

5.1.2 Acoustic

For reverberant acoustic field elements of the tolerances should be in accordance with those in Method 402 Acoustic Noise.

5.1.3 Temperature

For non transitional temperature elements of the test the tolerances should be in accordance with those in Method 301, para. 7.3(a). For temperature transitions the tolerances should be written in the Test Instructions.

5.1.4 Duration

The test duration shall be within +/-2% or one minute of the specified requirement whichever is the lesser.

5.2 Control

The environmental parameters required to control the test conditions are stated in para.2.4.2. The derivation of these parameters is the subject of Annex A.

5.3 Installation Conditions

The installation conditions are included in para. 5.6 and supported by further detail in Annex B.

5.4 Effects of Gravity

If the performance of the materiel is affected by the direction of gravity then the correct mounting attitude should be adopted for the test item.

5.5 Preparation for Test

5.5.1 Preconditioning

Unless otherwise specified the test item should be stabilized to its initial conditions stipulated in the Test Instruction. See also Method 301, para. 9.

5.5.2 Inspection and Performance Checks

Inspection may be carried out before and after testing. The requirements of these inspections should be defined in the Test Instruction. If these checks are required during the test sequence then the time intervals at which these are required should also be specified.

5.6 Procedures

5.6.1 Precursor Test

A precursor trial shall be carried out on a representative item, as follows, in order to establish the control parameters:

Step 1. Use Method 302/305 as appropriate. (This will determine the response temperature of the test item to be used at the initiation of this test).

Step 2. Fit the representative item with internal instrumentation arranged as for measurement trials used to establish the service environment.

Step 3. Install the representative item in the reverberation chamber, as detailed in Para. 5.6.2, Steps 1, 2 and 4.

Step 4. In the event that internal access within the test item is not possible, externally instrument the representative item as specified in the Test Instruction. (The spectral data from these external locations may need to be used as a basis for vibration control for the operational test item).

Step 5. Apply acoustic noise, with mechanical vibration (to fill in the low frequency responses), until the required vibration spectra are obtained at the internal instrumentation sites.

Step 6. Record the acoustic sound pressure levels and vibration spectra necessary to achieve the required internal vibration responses.

Step 7. In all cases record and analyse the data as specified.

Step 8. Remove the representative item from the chamber.

5.6.2 Operational Test

The test item shall be subjected to the following procedure:

Step 1. Install the test item from its normal attachment points as specified in the Test Instruction.

Step 2. Arrange connections to the test item, such as cables, hoses, etc., so that they impose similar dynamic restraint and mass to that when the materiel is mounted in its operational condition.

Step 3. Install accelerometers and temperature sensors on the test item at the specified positions.

Step 4. Fit the temperature duct over the test item ensuring that a uniform gap is provided and that connections to the test item do not unduly obstruct this gap. The duct should not provide any additional restraint to the test item.

Step 5. Connect the temperature conditioning duct to the supply duct.

Step 6. Close the chamber, initiate the temperature conditioning system and stabilise the test item at the required temperature.

Step 7. Perform the test using the parameters determined in para. 5.6.1, Step 5 and with the required temperature profiles as specified in the Test Instruction.

Step 8. Note all the information as specified in the Test Instruction

Step 9. Remove the test item from the chamber and carry out the inspections stipulated in the Test Instruction.

6. FAILURE CRITERIA

The test item performance shall meet all appropriate specification requirements during and following the application of the test conditions.

ANNEX A

DERIVATION OF TEST PARAMETERS

1. SCOPE

1.1 This annex sets out a procedure by which acoustic, vibration and thermal test cycle severities can be established. The main application of the procedure is to derive test severities and test cycles for the testing of stores, missiles and other airborne weapons. The procedure may also be applicable to aircraft equipment provided the environments of prime concern are vibration or kinetic heating induced by aerodynamic flow. The severities derived using the procedure in this annex could also be adopted for mechanical vibration (e.g.: Test Method 401) when combined with thermal testing.

2. BASE DATA REQUIRED

2.1 The base data required to determine vibration and thermal test cycle severities are the installation details for the nominated aircraft, the sortie profiles, the number of each type of sortie and information on altitude/temperature conditions.

2.2 The sortie profiles need to be defined in terms of airspeed, altitude and time. Illustrative profiles are shown in Figure A1. Representative sortie profiles are frequently set out in the technical requirements specification for stores, missiles and other airborne weapons. Another source of suitable information is the aircraft manufacturer. Additionally a number of representative sortie profiles suitable for reliability testing are set out in Mil Hdbk 781 (Reference A1). Whatever the source conditions they should not exceed the capability of the carriage aircraft with the required weapons configuration.

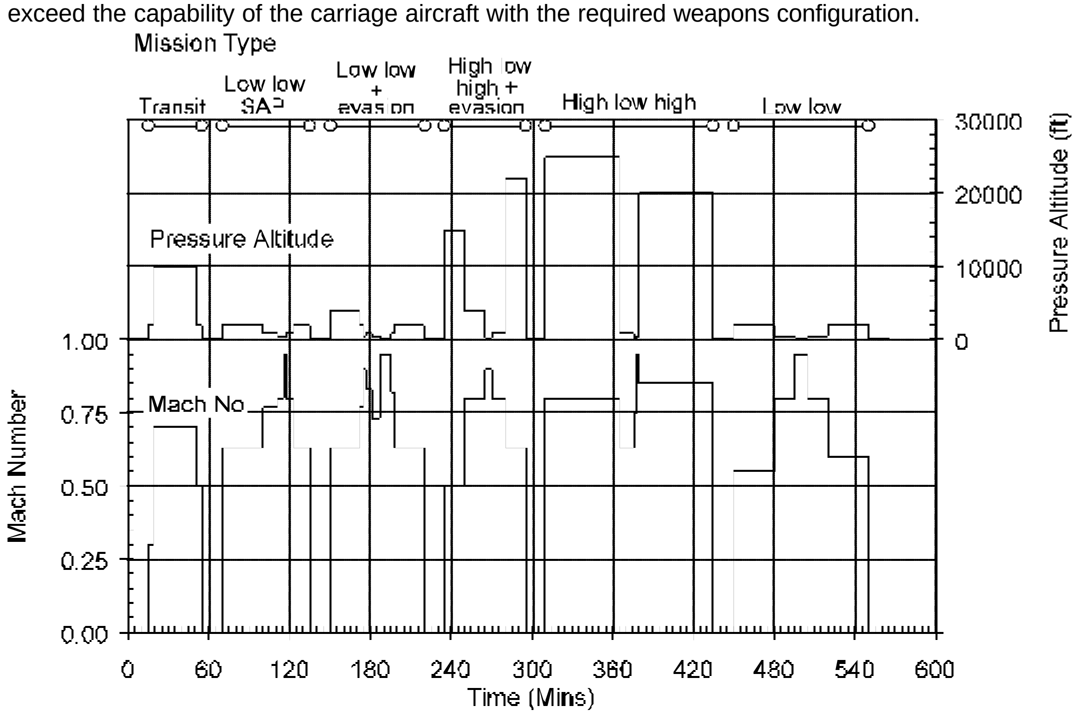

Figure A1: Flight profiles for six illustrative missions

	Number of missions per year	Duration of longest mission (mins)	Duration of shortest mission (mins)	Average mission duration (mins)	Percentage of total missions (%)	Percentage of total duration (%)
High level transit	1	40	40	40	3	2
Low level ground attack following standing air patrol	7	85	65	74	19	18
Low ground attack with evasion	7	85	60	69	19	17
Low ground attack	8	100	60	74	21	21
High low high strike with evasion	4	100	60	84	11	12
High low high strike	10	125	45	83	27	30

Table A1: Illustrative store usage

2.3 The proportion of each type of sortie within the operational life of the equipment must be established in order that this distribution can be reflected in the test conditions. Illustrative store usage is presented in Table A1. This information has been derived from UK data supplied by RAF Logistics Command. Such information is normally included in the technical requirements specification for stores, missiles and other airborne weapons.

2.4 Information on nominal altitude-temperatures conditions can be obtained from International Standard Atmosphere (ISA) tables. For extreme altitude-temperature conditions reference should be made to STANAG 2895. This STANAG also indicates the range of sea level temperature conditions likely to be experienced in world-wide weapon deployment.

3. TEMPERATURE PROFILE

3.1 For each phase of the sortie profile, the altitude condition will enable the ambient temperature to be determined. Using the aircraft speed at each altitude it is possible to calculate the skin recovery temperature from the following expressions:

$$Tr = Ta\left[1+\frac{r(\gamma-1)M^2}{2}\right]$$

where:

Tr = adiabatic thin skin temperature
Ta = ambient air temperature as a function of altitude
r = recovery time
γ = ratio of specific heats (1.4 for air)
M = Mach number
(Tr and Ta must be given in Kelvin or Rankine)

In the absence of other information, a recovery factor of 0.9 can usually be assumed. This reduces the above expression to : $T_r = T_a (1 + 0.18\, M^2)$

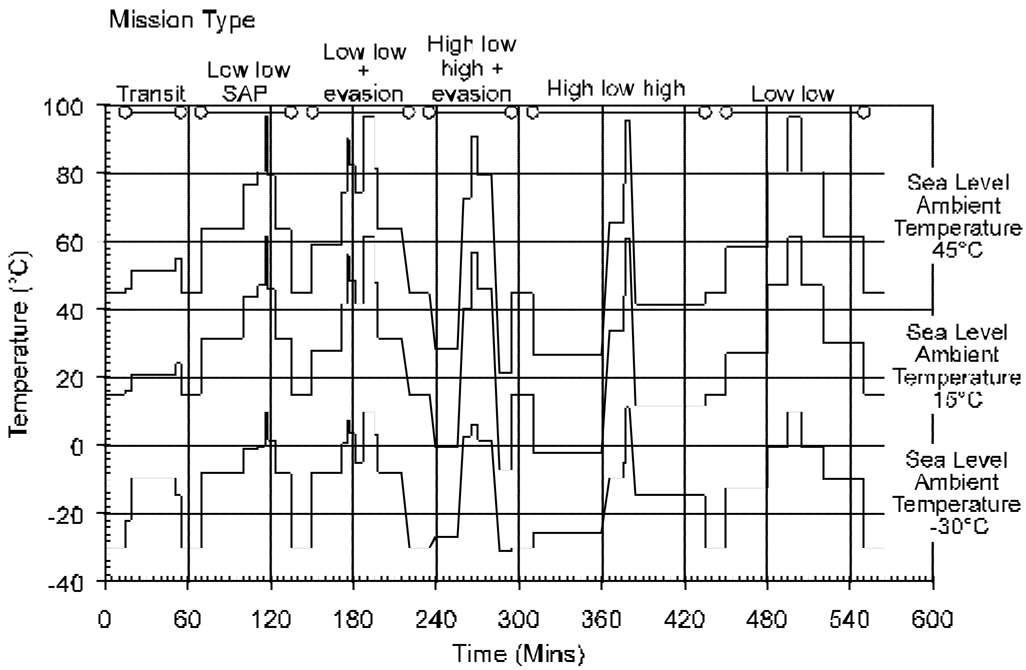

Figure A2 - Temperature profiles for six illustrative mission types

3.2 Having established the temperature condition for each phase of the sortie it will be possible to plot the temperature profile of the materiel skin for that sortie. Temperature profiles for six illustrative sorties are shown in Figure A2. As small variations in skin temperature will not be directly reflected in internal unit temperatures, it is possible to combine temperature conditions to produce a composite temperature sortie which will include both stable temperature conditions and associated rates of change of temperature at each stage.

3.3 Where it is required to cover world-wide operating conditions, the temperature cycle can be enhanced by the introduction of deviations to the cycle to represent various sea level temperatures as shown in Figure A2.

3.4 To maintain representative conditions, particularly for reliability testing purposes, the basic temperature cycle would not normally comprise only the extreme positive and negative sea level temperatures. The probability of operation away from sea level ambient temperature should be established to determine the number of cycles at each condition. Cycles based on hot and cold level temperatures should be interspersed with the ambient cycles such that each condition is evenly distributed over the life cycle of the store.

4. VIBRATION PROFILE

4.1 For each phase of the sortie profile, the aircraft pressure altitude and airspeed can be used to proportion flight vibration data into an appropriate profile. The vibration severities generated are intended to represent store responses occurring in flight. For the purpose of the test, combined acoustic and mechanical excitations are used to generate the required vibration response profile. The exact mix of acoustic and mechanical excitations required will depend upon facilities available.

4.2 The vibration severities experienced by a store vary throughout a sortie with changes in flight dynamic pressure, the variation of which may follow the profiles of Figure A3 for example. Vibration severities are also dependent upon a number of non-sortie dependent criteria such as store geometry and construction, measurement location and axis. Hence appropriate flight measured vibration data are required for the store when subjected to specific flight conditions. The measured severities can then be scaled according to the sortie profiles required for test purposes, such as those shown in Figure A4. Figure A5 shows a typical vibration spectrum that may be established from illustrative vibration data.

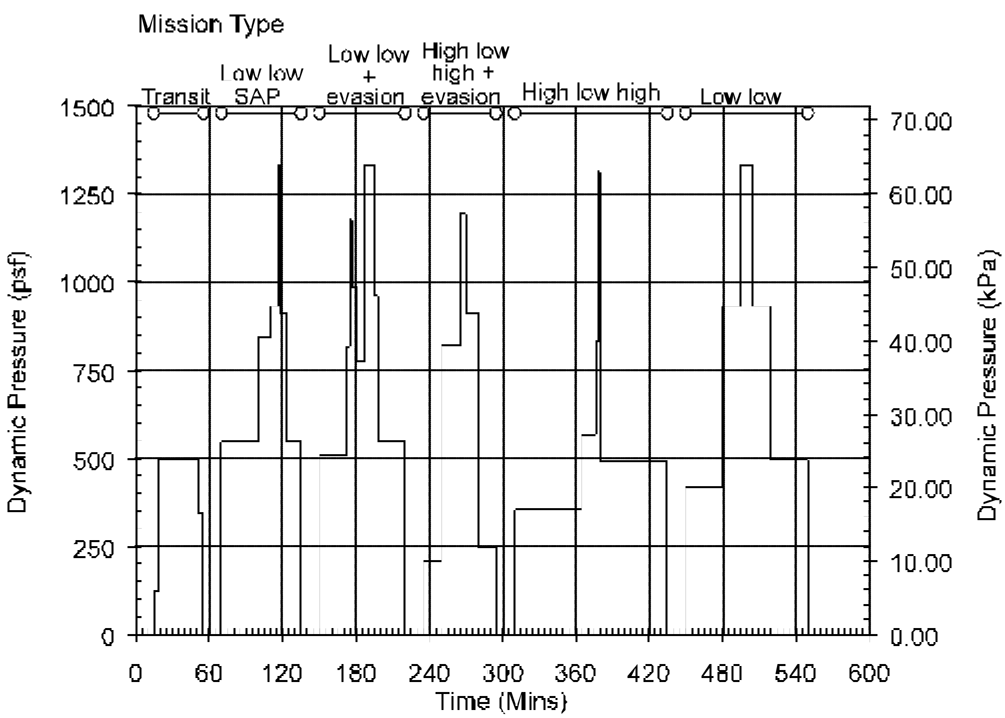

Figure A3: Equivalent free stream dynamic pressure Illustrative missions

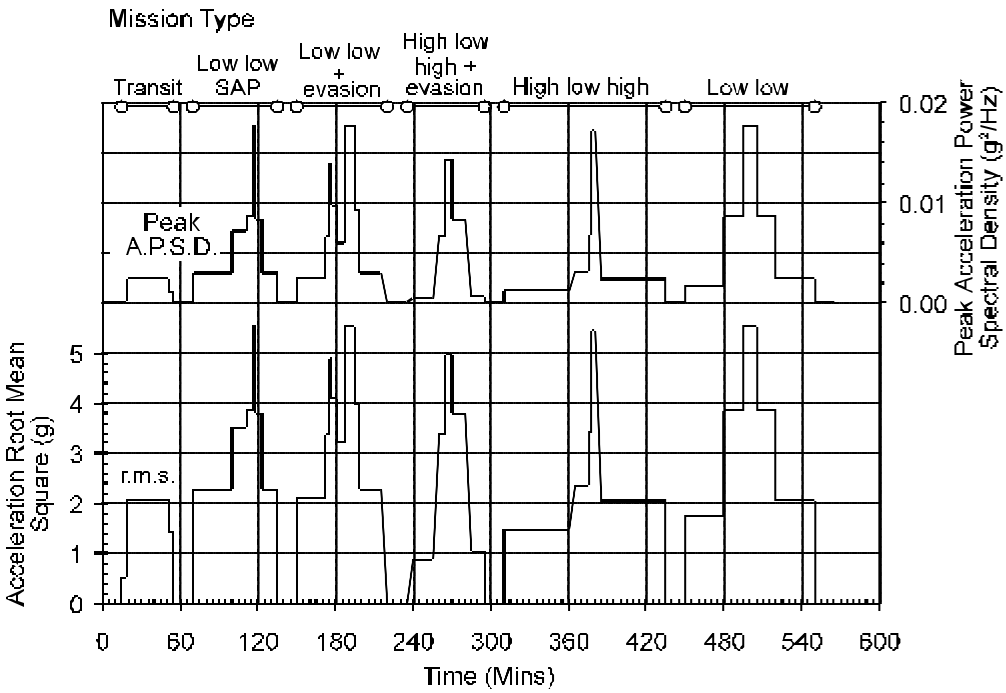

Figure A4: Illustrative vibration test severity profiles

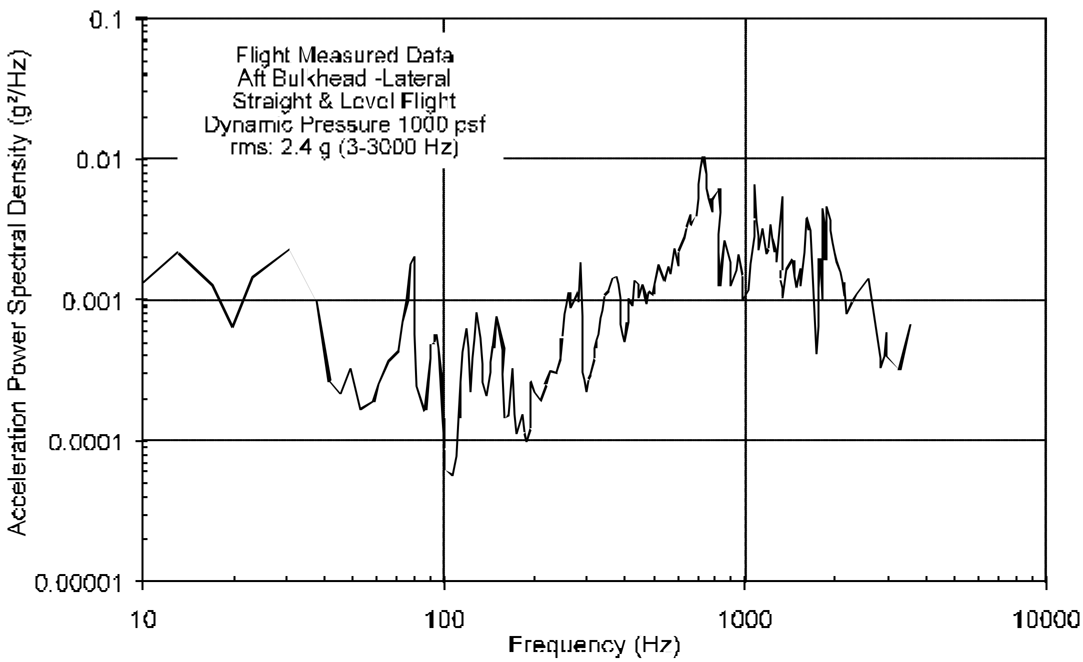

Figure A5: Illustrative vibration test severity profiles

4.3 The approximate relationships between flight dynamic pressure and vibration severities are as follows:

Acceleration rms = Bq

Acceleration PSD = Cq2

Where B and C are constants for a given aircraft/store configuration and q is flight dynamic pressure.

4.4 The relationship between flight dynamic pressure (q) with aircraft velocity and altitude is given by:

Dynamic pressure $$q = \frac{1}{2}\rho_0 V^2 = \frac{1}{2}\gamma P M^2$$

Where ρ_0 = atmospheric density at sea level ((kg/m^3)

V = equivalent air speed (ms^{-1})

P = air pressure at specified altitude (Pa)

M = true Mach number of aircraft

γ = ratio of specific heats = 1.4

For ISA conditions:

$q = 70.9\ M^2(1-2.256 \times 10^{-5}h)^{5.2561}$ kPa, (h = altitude in meters)

or

$q = 1480\ M^2(1-6.875 \times 10^{-6}h)^{5.2561}$ lb/ft^2, (h = altitude in feet)

4.5 In the absence of suitable measured flight vibration data alternative information can be derived from AECTP 200 Leaflet 246/2.

5. REFERENCE

Mil Hdbk 781 Reliability Test Methods, Plans, and Environments for Engineering Development, Qualification and Production, October 1987.

ANNEX B

FACILITY REQUIREMENTS

1. INTRODUCTION

This test is designed to provide a close approximation to the flight vibration and temperature environment seen by the internal components of assembled materiel carried externally on fixed wing aircraft.

2. VIBRATION CONDITIONS

The main source of vibration in service is the aerodynamic excitation acting over the total exposed surface of the materiel. Under test conditions this is simulated by the acoustic field of a reverberation chamber.

Acoustic excitation at low frequencies in a reverberation chamber is normally limited by the size of the chamber, the low frequency cut off of the noise generation system and the limited power availability. Additionally the very low frequencies, that result for example from the wing and pylon bending and torsional modes, are mechanically coupled through the attachment interface. For these reasons, low frequency energy should be applied to the test item by means of a mechanical vibrator operating in the nominal frequency range of 5 to 100 Hertz.

Mechanical vibration is applied via a light coupling connected to a strong point on the test item. This single point coupling should be rigid in the axis of vibration but allow lateral motion of the test item.

The acoustic and mechanical stimuli are adjusted to achieve the required vibration response at the specified internal location(s).

3. TEMPERATURE CONDITIONS

The normal method of generating high intensity noise in a reverberation chamber involves the use of a relatively high airflow through the chamber. In order to achieve the required temperature conditions at the test item skin, it is, therefore, necessary to enclose the test item and to control the temperature within that enclosure. This enclosure must be effectively transparent to the acoustic noise.

To achieve rapid changes of temperature at the test item skin and economy of thermal energy, it is preferred that the acoustically transparent enclosure be connected into a closed loop with the heat exchanger(s).

Temperature control will normally be established with a temperature sensor attached to a section of the external skin of the test item. The capacity of the facility should be sufficient to ensure that the thermal response of this skin section follows the highest rate of change of temperature within the tolerance specified.

4. FACILITY DESIGN CONSIDERATIONS

The reverberation chamber construction must include sufficient mass and damping such that the noise spectrum is not unduly influenced by vibration of the chamber surfaces. This can be achieved by ensuring that the chamber wall fundamental resonance frequencies are less than the lowest acoustic frequency.

Low frequencies are applied mechanically, hence the low frequency response of the chamber is not as critical as for a standard acoustic test. Hence, the minimum chamber size for a given vibration response spectrum may be selected for a cut-off frequency at or below the cross over between mechanical and acoustic excitation. Chamber dimensions required to accommodate the test item might be the limiting factor and the ratio of the major dimensions of the chamber must provide for adequate modal density at the lowest acoustic noise frequency.

The section of temperature conditioning air ducting within the chamber should be constructed to survive long periods of exposure to the acoustic noise conditions. Additionally, it may be desirable to incorporate noise attenuation within the external ducting to minimize the noise transmission to areas outside the chamber.

METHOD 414

HANDLING

TABLE OF CONTENTS

ANNEX A : GUIDANCE FOR INITIAL TEST SEVERITY

METHOD 414

HANDLING

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the environment incurred by systems, subsystems and units, hereafter called materiel, during loading, unloading and handling.

1.2 Application

This test is applicable where materiel is required to demonstrate its adequacy to resist the specified handling environment without unacceptable degradation of its functional and/or stuctural performance.

1.3 Limitations

This method is not intended to simulate basic shock, blast environments, transportation, nor safety drop conditions. Safety drop test for munitions are covered by STANAG 4375.

2. GUIDANCE

2.1 Effect of Environment

The following list is not intended to be all inclusive but provides examples of problems encountered during handling and dropping of materiel.

(1) Structural deformation

(2) Cracking and rupturing

(3) Loosening of fasteners

(4) Loosening of parts or components

2.2 Use of Measured Data

Not applicable.

2.3 Sequence

Drop and handling test may be performed anytime in the test program. The responsible authority will determine its place in the test sequence.

2.4 Test Procedures

The choice of test procedure is governed by the test purpose. This should be identified by the tailoring process described in AECTP 100.

2.5 Type

Special test procedures are used to simulate the in-service environments such as loading, unloading and handling of materiel.

2.5.1 Drop

This procedure is intended to determine if the test item is capable of withstanding shocks normally induced by loading and unloading of materiel and not those induced during transportation.

2.5.2 Horizontal Impact

This procedure is intended to determine the ability of materiel to withstand horizontal impacts encountered during loading and unloading of materiel, i.e., collisions when swinging on a crane. It is not intended to simulate materiel transportation environment.

2.5.3 Bench Handling

This procedure shall be used to determine the ability of materiel to withstand shock encountered during operations such as maintenance, calibration and servicing. This procedure need not be used if it can be demonstrated that the structural response of the materiel from the drop test are of a higher level.

3. SEVERITIES

See Annex A.

4. INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- Identification of test item
- Definition of test item
- Definition of test severity
- Test type(s) (bench handling, impact or drop)
- Packaging conditions, if applicable
- Axes and senses in which impact is applied
- Operating checks: initial, final
- Orientation relative to gravity
- Details required to perform test
- Failure criteria

5. TEST CONDITIONS

5.1 Tolerances

The tolerances on drop height impact velocity and test item inclination angle are ± 3%, unless otherwise specified in the Test Instruction.

5.2 Procedure 1 - Drop

The test facility includes an instantaneous release device, for example, a hook or wire to be cut, from which the test item is suspended. Unless specified in the Test Instruction, the impact-surface should be constructed of a layer of pinewood 5 cm thick bearing directly on a minimum 10 cm thick concrete stand for weights of up to 500 kg. For greater weights, a suitable thick concrete should be used.

NOTE: If the test item is to be packaged, the item shall be within the package container during testing. If the equipment can be transported with or without a container, the transit drop test shall be conducted for both cases.

Step 1. Make the initial checks on the test item in accordance with test instruction.

Step 2. Install the test item in the conditions required by the type of test: in its container, casing, on a frame or unequipped.

Step 3. Make the drops in accordance with par.2 of Annex A.

Step 4. After each drop make the final checks (in accordance with test instruction) and note the condition of the test item.

5.3 Procedure 2 - Horizontal Impact

The test apparatus shall be capable of simulating the horizontal impact of the test item. Unless specified in the Test Instruction, the impact surface shall be of a similar stiffness as in Procedure 1.

NOTE: When the attitude of the test item with respect to gravity is not important, the drop test may be used.

Step 1. Make the initial checks on the test item.

Step 2. Install the test item in the conditions required by the Test Instructions.

Step 3. The test item shall strike the test surface in accordance with the conditions of paragraph 3 of Annex A.

Step 4. After each impact, make the final checks as per test instructions and note condition of test item.

5.4 Procedure 3 - Bench Handling

The test items shall be placed on a horizontal, solid wooden bench top at least 4 cm thick (the thickness of the bench top is specified for standardization purposes).

NOTE: The test item shall not be packaged or within a container.

Step 1. Using one edge as a pivot, lift the opposite edge of the test item until one of the following conditions occurs (whichever occurs first):

a. The test item forms an angle of 45 degrees with the horizontal bench top.

or

b. The lifted edge of the test item has been raised 10 cm above the horizontal bench top. Ten centimeters is believed to be the average height one corner of an equipment will be raised during servicing and is used for standardization purposes.

Step 2. Let the test item drop back freely to the horizontal bench top. Repeat using other edges of the same horizontal face as pivot points, for a total of four drops.

Step 3. Repeat steps 1 and 2 with the test item resting on other faces until it has been dropped for a total of four times on each face on which the test item could be realistically placed during servicing.

Step 4. Step 4 After each impact make final checks as per test instruction and note condition of test item.

6. FAILURE CRITERIA

The test item shall meet all of the appropriate specification requirements following the test.

ANNEX A

GUIDANCE FOR INITIAL TEST SEVERITY

1. SCOPE

This annex is intended to provide the rationale behind the information contained in the preceding procedures and to give guidance for selecting test and severities.

2. DROP TEST

The standard shock test for packaged materiel is a drop test in which the test item is dropped from a predetermined height onto a rigid surface. The height of the drop is determined by the type of handling the test item may receive during shipment. For example, packages from 0 to 23 Kg may be considered within the "one man throwing limit"; i.e., test items of such weight may be thrown easily onto piles or in other ways severely mishandled due to their light weight. Packages weighing between 23 and 46 Kg may be considered within a "one man carrying limit"; such packages are somewhat heavy to be thrown but can be carried and dropped from a height as great as shoulder height. A "two man dropping limit" may apply to a weight range between 46 to 92 Kg; the corresponding drop height for this mode of handling may be waist height. A further range may be from 92 to 460 Kg; packages in this range would be handled with light cranes or lift trucks and may be subjected to impacts from excessive lifting or lowering actions. Finally, very heavy packages weighing over 460 Kg would be handled by heavier materiel with correspondingly more skill; any drops would be from very small heights. Similarly, the size of the package classifies the type of handling into one man, two men, light materiel, or heavy materiel with corresponding drop heights. Thus, the drop heights for these tests are derived from the type of handling to which the package is more likely to be subjected during a shipping cycle; the type of handling is dependent on the size and weight of the package.

In addition to drop heights that vary with package size and weight, another factor in handling testing is the orientation of the package at impact. For example, small, light-weight packages are likely to be subjected to free fall drops onto sides, edges, and corners of the package. Larger, heavier packages handled by light or heavy materiel are likely to encounter drops of the type where one end rests on the floor and the other end is dropped (bottom rotational drop).

The pertinent drop heights are summarized in Table A1.

3. HORIZONTAL IMPACT

Use impact velocity of 2.5 m/s or height of drop of 0.32 m. with 2 impacts per face.

4. BENCH HANDLING

See para. 5.4

Weight of Test Item and Cases	Largest Dimensions	Notes	Height of Drop	Number of Drops
Under 45 kg Manpacked or Transportable	Under 0.91 m	A/D	1.22 m	Drop on each face,edge, and corner. Total of 26 Drops
	0.91 m and over	A/D	0.76 m	
45 to 90 kg Inclusive	Under 0.91 m	A	0.76 m	Drop on each corner Total of 8 Drops
	0.91 m and over	A	0.61 m	
90 to 450 kg Inclusive	Under 0.91 m	A	0.61 m	
	0.91 to 1.52 m	B	0.91 m	
	Over 1.52 m	B	0.91 m	
Over 450 kg	No limit	C	0.46 m	Drop on each bottom edge. Drop on bottom face or skids. Total of 5 Drops

TABLE A1

NOTES

A. The test item shall be so oriented so that upon impact a line from the center of gravity of the test item to the point of impact is perpendicular to the impact surface.

B. The longest dimension of the test item shall be parallel to the floor. The item shall be supported at the corner of one end by a block 0.125 m in height, and at the other corner along the same edge by a block 0.30 m in height. The lowest opposite end of the case then shall be raised to the specific height at the lowest unsupported corner and allowed to fall freely.

C. While in the norm al position, the case and contents shall be subjected to the edgewise drop test as follows (if the normal transit position is unknown, the case shall be so oriented that the two longest dimensions are parralel to the floor). One edge of the base of the case shall be supported on a sill 0.15 m in height. The opposite edge shall be raised to the specific height and alowed to fall freely.

D. The 26 drops may be divided among no more than five test items.

E. Horizontal Impact: Use impact velocity of 2.5 m/s or height of drop of 0.32 m. Two impacts per face.

METHOD 415

PYROSHOCK

TABLE OF CONTENTS

ANNEX A : TECHNICAL GUIDANCE

METHOD 415

PYROSHOCK

1 SCOPE

1.1 Purpose

The purpose of this test method is to replicate the effects of complex high amplitude and high frequency transient responses which are incurred by systems, subsystems and units, (hereafter called materiel) during the specified operational conditions under exposure to pyroshock from pyrotechnic (explosive or propellant-activated) devices.

1.2 Application

This method is applicable where materiel is required to demonstrate its adequacy to resist the pyroshock environment without unacceptable degradation of its functional and/or structural performance. AECTP's 100 and 200 provide additional guidance on the selection of a test procedure for pyroshock environment.

1.3 Limitations

Because of the highly specialised nature of pyroshock, apply it only after giving careful consideration to information contained in the paragraphs below. Supplemental information, that may be helpful, is contained in references f, g, h, n and o listed in Annex A. In general it may not be possible to simulate some of the actual operational service pyroshock environments because of fixture limitations or physical constraints that may prevent the satisfactory application of the pyroshock to the test materiel.

a. This method does not include the shock effects experienced by materiel as a result of any mechanical shock, transient vibration, shipboard shock or EMI. For these types of shocks see the appropriate methods in this standard.

b. This method does not include the effects experienced by fuse systems that are sensitive to shock from pyrotechnic devices. Shock tests for safety and operation of fuses and fuse components may be performed in accordance with other applicable national and international standards specifically addressing fuse system environmental testing.

c. This method does not include special provisions for performing pyroshock tests at high or low temperatures.

d. This method is not intended to be applied to manned space vehicle testing (see references h and n in Annex A.).

e. This method does not address secondary effects such as induced blast, EMI and thermal effects.

f. This method does not address effects of ballistic shock on materiel.

2 GUIDANCE

2.1 Introduction

Because of the highly unique form of the environment, introductory discussion is provided in an attempt to characterise the environment.

2.1.1 Rationale for Testing to Pyroshock

Pyroshock tests involving pyrotechnic (explosive - or propellant-activated) devices are performed to

a. provide a degree of confidence that materiel can structurally and functionally withstand the infrequent shock effects caused by the detonation of a pyrotechnic device on a structural configuration to which the materiel is mounted.
b. experimentally estimate the materiel's fragility level relative to pyroshock in order that shock mitigation procedures may be employed to protect the materiel structural and functional integrity.

2.1.2 Definition of Pyroshock

"Pyroshock" is often referred to as "pyrotechnic shock." For purposes of this document, initiation of a "pyrotechnic" device will result in an effect that is referred to as a "pyroshock". Pyroshock refers to the localised intense mechanical transient response caused by the detonation of a pyrotechnic device on adjacent structure.

A number of devices are capable of transmitting such intense transients to a materiel. In general a pyroshock is caused by (1) an explosive device, or (2) a propellant activated device (releasing stored strain energy) coupled directly into the structure; (for clarification, a propellant activated device includes things such as a clamp that releases strain energy causing a structure response greater than that obtained from the propellant explosion alone.) In general, the sources may be described in terms of their spatial distribution - point sources, line sources and combined point and line sources (reference n Annex A). Point sources include explosive bolts, separation nuts, pin pullers and pushers, bolt and cable cutters and pyro-activated operational hardware. Line sources include flexible linear shaped charges (FLSC), mild detonating fuses (MDF) and explosive transfer lines. Combined point and line sources include V-band (Marmon) clamps. The loading from the pyrotechnic device may be accompanied by the release of structural strain energy from structure preload or impact amongst structural elements as a result of the activation of the pyrotechnic device. This method is to be used to evaluate materiel likely to be exposed to one or more pyroshocks in its lifetime.

Pyroshocks are generally limited to a frequency range between 100 Hz and 1,000,000 Hz, and time duration from 50 microseconds to not more than 20 milliseconds. Acceleration response amplitudes to pyroshock may range from 300g to 300,000g. The acceleration response time history to pyroshock will, in general, be very oscillatory and have a substantial rise time, approaching 10 microseconds. In general, the pyroshocks generate material stress waves that will excite materiel to respond to very high frequencies with wavelengths on the order of sizes of micro electronic chip configurations. Because of the limited velocity change in the structure brought about by firing of the pyrotechnic device and the localised nature of the pyrotechnic device, structural resonance's of materiel below 500 Hz will normally not be excited and the system will undergo very small displacements with small overall structural damage. The pyroshock acceleration environment in the neighbourhood of the materiel will usually be highly dependent upon the configuration of the materiel. The materiel or its parts may be in the near-field or far-field of the pyrotechnic device with the pyroshock environment in the near-field being the most severe, and that in the far-field the least severe.

2.1.3 Pyroshock Characteristics

"Pyroshock" is a physical phenomenon characterised by the overall material and mechanical response at a structure point from either (a) an explosive device, or (b) a propellant activated device. Such a device produces extreme local pressure (with perhaps heat and electromagnetic emission) at a point or along a line. This extreme local pressure provides a near instantaneous generation of local high-magnitude non-linear material strain rates accompanied by the transmission of high-magnitude/high frequency material stress waves that produce high acceleration/low velocity short duration response at distances from the point or line source. The characteristics of pyroshock are:

a. near-the-source stress waves in the structure caused by high material strain rates (non-linear material region) that propagate into the near-field and beyond;

b. high frequency (100 Hz -1,000,000 Hz) and very broadband frequency input;

c. high acceleration (300g-300,000g) but low structural velocity and displacement response;

d. short-time duration (<20 msec);

e. high residual structure acceleration response (after the event);

f. point source or line source input (input is highly localised);

g. very high structural driving point impedance (P/v, where P - the large explosive force or pressure, and v - the small structural velocity). Right at the source the impedance could be substantially less if the material particle velocity is high;

h. response time histories away from the source that are highly random in nature, i.e., little repeatability and very dependent on the configuration details;

i. response at points on the structure greatly affected by structural discontinuities;

j. structural response may accompanied by substantial heat and electromagnetic emission (from ionisation of gases during explosion);

2.1.4 Pyroshock Intensity Classification

The nature of the response to pyroshock suggests that the materiel or its components may be classified as being in the near-field or far-field of the pyrotechnic device. The terms "near-field," and "far-field" relate to the shock intensity at the response point and such intensity is a function (in general unknown) of the distance from the source and the structural configuration between the source and the response point.

1) Near-field. In the near-field of the pyrotechnic device the response is governed by the structure material stress wave propagation effects. In the near-field of an intense pyrotechnic device, the materiel or any portion of the materiel is within 15 cm (6 in) of point of detonation of the device or a portion of it (in the case of a line charge). If there are no intervening structural discontinuities, the materiel may be expected to experience

peak accelerations in excess of 5000 g and substantial spectral content above 100,000 Hz. The near-field of a less intense pyrotechnic device can be considered to be within 7.5 cm (3 in) of the point of detonation of the device or a portion of it with subsequent reduction in the peak acceleration levels and spectral levels.

2) Far-field. In the far-field of the pyrotechnic device the pyroshock response is governed by a combination of material stress wave propagation effects and structural resonance response effects. For an intense pyrotechnic device, the materiel or any portion of the materiel is beyond 15 cm (6 in) of point of detonation of the device or a portion of it (in the case of a line charge). If there are no intervening structural discontinuities, the materiel may be expected to experience peak accelerations between 1000g and 5000 g and substantial spectral content above 10,000 Hz. The far-field of a less intense pyrotechnic device can be considered to be beyond 7.5 cm (3 in) of the point of detonation of the device or a portion of it with subsequent reduction in the peak acceleration levels and spectral levels. On occasion, the far-field of a pyrotechnic device is characterised by the mechanical structural resonance response effects above. If there are no intervening structural discontinuities, the materiel may be expected to experience peak accelerations below 1000g and most spectral content below 10,000 Hz.

2.1.5 Effects of Environment (Pyroshock)

Following is a discussion with list, not intended to be all inclusive, providing examples of problems that could occur when materiel is exposed to pyroshock.

In general, pyroshock has the potential for producing adverse effects on all electronic materiel. The level of adverse effects increases with the level and duration of the pyroshock, and decreases with the distance from the source (pyrotechnic device) of the pyroshock. Duration's for pyroshock that produce material stress waves with wavelengths that correspond with the natural frequency wavelengths of micro electronic components within materiel will enhance adverse effects. In general, the structural configuration merely transmits the elastic waves and is unaffected by the pyroshock. Examples of problems associated with pyroshock include:

a. materiel failure as a result of destruction of the structural integrity of micro electronic components,

b. materiel failure as a result of relay chatter;

c. materiel failure as a result of circuit card malfunction, circuit card damage and electronic connector failure. On occasion, circuit card contaminants having the potential to cause short circuits may be dislodged under pyroshock.

d. materiel failure as a result of cracks and fracture in crystals, ceramics, epoxies, or glass envelopes.

2.2 Use of Measured Data

This section provides background and guidance on the use of measured data in testing for pyroshock and comment on cases in which there is no measured data. It is important to note that for pyroshock, pyro-devices are "designed into" the overall materiel configuration and must perform for a specific purpose. In this case it is easier to obtain "measured data" during such times as laboratory development. On occasion measured pyroshock data may be quite readily available and needs to be processed and utilised to the greatest extent possible in test instruction development.

2.2.1 Measured data available from pyroshock

1) If measured data are available, the data may be processed utilising the Shock Response Spectra (SRS), Fourier Spectra (FS) or the Energy Spectral Density (ESD). For engineering and historical purposes, the SRS has become the standard for measured data processing. In the discussion to follow it will be assumed that the SRS is the processing tool. In general, the maximax SRS spectrum (absolute acceleration or pseudo-velocity) is the main quantity of interest. Determine the shock response spectrum required for the test from analysis of the measured environmental acceleration time history. After carefully qualifying the data, to make certain there are no anomalies in the amplitude time histories compute the SRS. Reference f of Annex A provides helpful information regarding the qualifying of pyroshock data. The analyses will be performed for Q = 10 at a sequence of natural frequencies at intervals of at least 1/6 octave and no finer than 1/12th octave spacing to span at least 100 to 20,000 Hz, but not to exceed 100,000 Hz. When a sufficient number of representative shock spectra are available, employ an appropriate statistical technique (in general an enveloping technique) to determine the required test spectrum. Annex C of Method 503 references the appropriate statistical techniques. In general, parametric statistics can be employed if the data can be shown to satisfactorily fit an assumed underlying probability distribution. (For example, in some standards the test levels are based upon a maximum predicted environment defined to be equal to or greater than the 95th percentile value at least 50 percent of the time - this is a tolerance interval approach. When a normal or lognormal distribution can be justified, Annex C of Method 503 taken from reference i in Annex A provides a method for estimating such a test level.)

2) When insufficient data are available for statistical analysis, use an increase over the maximum of the available spectral data to establish the required test spectrum to account for variability of the environment. The degree of increase is based upon engineering judgement and should be supported by rationale for that judgement. In these cases it is often convenient to envelop the SRS by computing the maximax spectra over the sample spectra and proceed to add a +6dB margin to the SRS maximax envelope.

3) When employing the pyroshock test, determine the effective transient duration, Te , from the time histories of the environmental or by just good engineering judgement. For all procedures, the pyroshock shock amplitude time history used for the SRS analysis will be Te in duration. In addition, measurement data will be collected for a duration, Te, just prior to the pyroshock, and duration, Te, just after the pyroshock for subsequent analysis. In general, each individual axis of the three orthogonal axes will have approximately the same shock test SRS and average effective duration as a result of the omni-directional properties of a pyroshock in Procedure I and Procedure II. For Procedure III, the form of shock test SRS may vary with axes. An SRS shaker shock technique (complex transient) must be employed when using Procedure IV. The

classical shock pulse, e.g., half-sine, terminal-peak saw tooth, etc., forms of shock must not be used for testing in this procedure.

2.2.2 Measured data not available from pyroshock

If a data base is not available for a particular configuration, the tester must rely upon configuration similarity and any associated measured data for prescribing a pyroshock test. Because of the sensitivity of both the pyroshock to the system configuration and the wide variability inherent in pyrotechnic shock measurements, the tester must proceed with caution. As a basic guide for pyroshock testing, Figure 415-10 from reference n in Annex A provides SRS estimates for four typical aerospace application pyrotechnic point source devices. Figure 415-11 from reference n provides information on the attenuation of the peaks in the SRS, and of the ramp in the SRS of the point sources in Figure 415-10 with distance from the source. Information in Figure 415-10 and Figure 415-11 came from reference p of Annex A. Reference p also recommends that the attenuation of the peak SRS across joints be taken to be 40% per joint for up to three joints, and that there be no attenuation of the ramp portion of the SRS. Figure 415-12 provides the degree of attenuation of the peak time history response as a function of the shock path distance from the source for seven aerospace structural configurations. This information was summarised from reference q of Annex A. The SES scaling law or the RLDS scaling law (paragraph 3.2.2.) may provide guidance. In most cases, either Procedure II or Procedure III are the optimum procedures for testing, with the smallest risk of either substantial undertest or gross overtest. If Procedure I is not an option, the tester must proceed with caution with Procedure I or Procedure III according to the guidelines within this method (other helpful information concerning these procedures is contained in reference g of Annex A). In reality, a test transient is deemed suitable if it's SRS equals or exceeds the given SRS requirement over the minimum frequency range of 100 to 20,000 Hz and the duration of the test transient is within 20% of that of the normal pyroshock response duration for other configurations.

2.3 Sequence

Since pyroshock is normally experienced near the end of the life cycle, except otherwise noted in the life cycle profile, normally schedule pyroshock tests late in the test sequence unless the materiel must be designed to survive extraordinarily high levels of pyroshock for which vibration and other shock environments are considered nominal. Pyroshock tests can be considered independent of the other tests because of their unique specialised nature and consideration of combination environment tests will be rare. It is good practice to expose a single test materiel to all relevant environmental conditions in turn if independence of other tests can not be confidently substantiated.

In addition, perform tests at room ambient temperature unless otherwise specified or there is reason to believe either operational high temperature or low temperature may enhance the pyroshock environment.

This method does not include sequence related guidance for unplanned test interruption as a result of pyroshock device or mechanical test equipment malfunction (in cases in which the pyroshock is being mechanically simulated). Generally, if the pyroshock device malfunctions or interruption occurs during a mechanical shock pulse, repeat that shock pulse. Care must be taken to ensure stresses induced by the interrupted shock pulse do not invalidate subsequent test results. In particular, check materiel functionality and inspect the overall integrity of the materiel to ensure pre-shock test materiel integrity. Record and analyse data from such interruptions before continuing with the test sequence.

2.4 Choice of Test Procedures

The choice of test procedures is governed by many factors including the in-Service environment and materiel type. These and other factors are dealt with in the General Requirements - AECTP 100 and in the definition of Environments in AECTP 200.

This method includes four test procedures.

a. Procedure I - Near-Field with Actual Configuration. Replication of pyroshock for the near-field environment using the actual materiel and the associated pyrotechnic shock test device configuration.

b. Procedure II - Near-Field with Simulated Configuration. Replication of pyroshock for the near-field environment using the actual materiel but with the associated pyrotechnic shock test device isolated from the test item, e.g., by being mounted on the back of a flat plate. (This normally will minimise testing costs because less materiel configurations and/or platforms associated with the test item will be damaged. This can be used for repeated tests at varying levels.)

c. Procedure III - Far-Field Using Mechanical Test Device. Replication of pyroshock for the far-field environment with a mechanical device that simulates the pyroshock peak acceleration amplitudes and frequency content (other than an electrodynamic shaker because of frequency range limitations of the shaker)

d. Procedure IV - Far-Field Using Electrodynamic Shaker. Replication of pyroshock for the far-field environment using an electrodynamic shaker to simulate the comparatively low frequency structural resonant response to the pyroshock.

2.4.1 Procedure selection considerations

Based on the test data requirements, determine which test procedure is applicable. Select pyroshock Procedures I, II, III or IV. In most cases the selection of the procedure will be dictated by the actual materiel configuration, carefully noting any structural discontinuities that may serve to mitigate the effects of the pyroshock on the materiel. In some cases the selection of the procedure will be driven by test practicality. Consider all pyroshock environments anticipated for the materiel during its life cycle, both in its logistic and operational modes. When selecting procedures, consider:

a. The operational purpose of the materiel. From the requirement documents, determine the functions to be performed by the materiel either during or after exposure to the pyroshock environment.

b. The natural exposure circumstances for pyroshock. Determine if the materiel or portion of the materiel lies within the near-field or far-field of the pyrotechnic device. If the materiel or a portion of the materiel lies within the near-field of the pyrotechnic device, no special isolation of the materiel exists and, if there are no measured field data, apply only Procedure I or II. If no portion of the materiel lies within the far-field of the pyrotechnic device and measured field data exist, apply Procedure III if the processed data supports the amplitude and frequency range capabilities of the test devices. If the entire materiel lies within the far-field and is subject to structural response only, apply Procedure IV if the processed data supports the comparatively large velocity/displacement low frequency range (to 2000 Hz) of an electrodynamic shaker. If the processed data does not support the limitations of the electrodynamic shaker, apply Procedure III. In any case, one test will be considered sufficient for testing over the entire amplitude and frequency range of exposure of the materiel. Do not break up any measured or predicted response to pyroshock into separate amplitude or frequency ranges and apply different techniques in testing in each separate amplitude or frequency range.

c. Operational purpose. The test data required to determine whether the operational purpose of the materiel has been met.

d. Procedure sequence. Refer to paragraph 2.3.

2.5 Types of Pyroshock

2.5.1 Procedure I - Near-Field with Actual Configuration

Procedure I is intended to test materiel (including mechanical, electrical, hydraulic, and electronic) in its functional mode and actual configuration (materiel/pyrotechnic device physical relationship), and to ensure it can survive and function as required when tested using the actual pyrotechnic test device in its intended installed configuration. In Procedure I it is assumed that the materiel or a portion of the materiel resides within the near-field of the pyrotechnic device.

2.5.2 Procedure II -Near-Field with Simulated Configuration

Procedure II is intended to test materiel (including mechanical, electrical, hydraulic, and electronic) in its functional mode but with a simulated structural configuration, and to ensure it can survive and function as required when in its actual materiel/pyrotechnic device physical configuration. In this procedure it is assumed that some part of the materiel lies within 15 cm (6 in) from some portion of an intense pyrotechnic device or within 7.5 cm (3 in) of a less intense pyrotechnic device. Every attempt should be made to use this procedure to duplicate the actual platform/materiel structural configuration by way of a full-scale test. If this is too costly or impractical, employ scaled tests provided that in the process of scaling important configuration details are not omitted. In particular, only the structure portion directly influencing the materiel may be involved in the test, provided it can be reasonably assumed that the remainder of the structure will not influence materiel response. On occasion, for convenience a special pyrotechnic testing device may be employed for testing the materiel, e.g., a flat steel plate to which the materiel is mounted and the pyrotechnic charge is attached.

2.5.3 Procedure III - Far-Field Using Mechanical Test Device

Pyroshock can be applied utilising conventional high acceleration amplitude/frequency test input devices. Reference g of Annex A provides a source of alternative test input devices, their advantages and limitations. In this procedure it is assumed that all parts of the materiel lie in the far-field of the pyrotechnic device, i.e., every part of the materiel is beyond 15 cm (6 in) of any part of an intense pyrotechnic device, and beyond 7.5 cm (3 in) of any part of a less intense pyrotechnic device. Consult reference g for guidelines and consideration for such testing.

2.5.4 Procedure IV - Far-Field Using Electrodynamic Shaker

Pyroshock can be applied utilising conventional electrodynamic shakers. In this procedure it is assumed that all parts of the materiel lie in the far-field of the pyrotechnic device, i.e., every part of the materiel is beyond 60 cm (24 in.) from any part of an intense pyrotechnic device, or beyond 30 cm (12 in) from any part of a less intense pyrotechnic device, and the materiel is subject to the structure platform resonant response alone. In all cases, it is necessary to verify, using in-service measurements, that the simulation using a shaker is representative of the platform resonant response alone.

3 SEVERITIES

3.1 General

When practicable, test levels and duration's will be "tailored" or established using projected service use profiles and other relevant data. Pyroshock events are "designed into" the overall materiel configuration with a well defined sequence of occurrence. When measured data are not available consult the references in Annex A or the technical guidance found in this annex. All information should be used in conjunction with the appropriate information given in AECTP 200. Having selected one of the four pyroshock procedures (based on the materiel's requirements documents and the tailoring process), complete the tailoring process by identifying appropriate parameter levels, applicable test conditions and applicable test techniques for that procedure. For pyrotechnic testing exercise extreme care in consideration of the details in the tailoring process. Base these selections on the requirements documents, the Life Cycle Environmental Profile, the Operational Environment Documentation, and information provided with this procedure. Consider the following when selecting test levels.

3.2 Test conditions - Shock spectrum transient duration and scaling

Derive the SRS and the effective transient duration, T_e, from measurements of the materiel's functional environment or, if available, from dynamically scaled measurements of a similar environment. Because of the inherent very high degree of randomness associated with the response to a pyroshock, extreme care must be exercised in dynamically scaling a similar event. For pyroshocks there are two known scaling laws for use with response from pyroshocks that may be helpful if used with care (references h, n of Annex A).

3.2.1 Pyroshock Source Energy Scaling (SES)

The first scaling law is the Source Energy Scaling (SES) where the SRS is scaled at all frequencies by the ratio of the total energy release of two different devices. For E_r and E_n the total energy in two pyrotechnic shock devices the relationship between the SRS processed levels at a given natural frequency f_n and distance D_1 is given by the following expression :

$$SRS(f_n | E_n, D_1) = SRS(f_n | E_r, D_1) * \sqrt{[E_n / E_r]}$$

In utilising this relationship, it is assumed that either an increase or decrease in the total energy of the pyrotechnic shock devices will be coupled into the structure in exactly the same way, i.e., excessive energy from one device will go into the structure as opposed to being dissipated in some other way, e.g., through the air.

3.2.2 Pyroshock Response Location Distance Scaling (RLDS)

The second scaling law is the Response Location Distance Scaling (RLDS) where the SRS is scaled at all frequencies by an empirically derived function of the distance between two sources. For D_1 and D_2, the distances from a pyrotechnic shock device the relationship between the SRS processed levels at a given natural frequency, f_n, is given by the following expression:

$$SRS\left(f_n \middle| D_2\right) = SRS\left(f_n \middle| D_1\right) \exp\left\{\left[-2x10^{-5} f_n^{\left(2.4 f_n^{-0.105}\right)}\right]\left[D_2 - D_1\right]\right\}$$

In utilising this relationship it is assumed that D_1 and D_2 can be easily defined as in the case of a pyrotechnic point source device. Figure 415.9 from reference h in Annex A displays the ratio of $SRS(f_n|D_2)$ to $SRS(f_n|D1)$ as a function of the natural frequency, f_n, for selected values of D_2-D_1. It is clear from this plot that as the natural frequency increases there is a marked decrease in the ratio for a fixed D_2-D_1 > 0 and as D_2-D_1 increases the attenuation becomes substantial. This scaling relationship when used for prediction between two configurations relies very heavily upon (1) similarity of configuration and (2) similarity of type of pyrotechnic device. Reference n of Annex A and the example provided in this reference should be consulted before applying this scaling relationship.

3.3 Information Concerning Specific Procedures - (Test axes, duration and number of shock events)

3.3.1 Procedure I - Near-Field with Actual Configuration

For Procedure I, subject the test item to a sufficient number of suitable shocks to meet the specified test conditions. The following guidelines may be applied. For materiel that is likely to be exposed only rarely to a given pyroshock event, perform one shock for each appropriate environmental condition. For materiel that is likely to be exposed more frequently to a given pyroshock event and there is little available data to substantiate the number of pyroshocks, apply three or more at each environmental condition based on the anticipated service use. A suitable test shock for each axis is one that yields an SRS that equals or exceeds the required test SRS over the specified frequency range when using a duration specified T_e value for the test shock time history, and when the effective duration of the shock is within twenty percent of the specified T_e value. Determine the SRS for Q = 10, and at least 1/6-octave frequency intervals. The objective of the test is to test the physical and functional integrity of the materiel under the actual pyroshock configuration in the near-field of the pyroshock device.

3.3.2 Procedure II - Near-Field with Simulated Configuration

For Procedure II, subject the test item to a sufficient number of suitable shocks to meet the specified test conditions. The following guidelines may be applied. For materiel that is likely to be exposed only rarely to a given pyroshock event, perform one shock for each appropriate environmental condition. For materiel that is likely to be exposed more frequently to a given pyroshock event and there is little available data to substantiate the number of pyroshocks, apply three or more shocks at each environmental condition based on the anticipated service use. A suitable test shock for each axis is one that yields an SRS that equals or exceeds the required test spectrum over the specified frequency range when using a duration specified T value for the test shock time history, and when the effective duration of the shock, T_e, is within twenty percent of the specified T value. Determine the maximax SRS for Q = 10, and at least 1/6-octave frequency intervals. The objective of the test is to test the structural and functional integrity of the materiel under a simulated pyroshock configuration in the near-field of the pyroshock device.

3.3.3 Procedure III - Far-Field Using Mechanical Test Device

For Procedure III, subject the test item to a sufficient number of suitable shocks to meet the specified test conditions. The following guidelines may be applied. For materiel that is likely to be exposed only rarely to a given pyroshock event, perform one shock for each appropriate environmental condition. For materiel that is likely to be exposed more frequently to a given pyroshock event and there is little available data to substantiate the number of pyroshocks, apply three or more at each environmental condition based on the anticipated service use. The measured response test requirements may be satisfied along more than one axis with a single test shock configuration. Consequently, it is conceivable that a minimum of three test shock repetitions will satisfy the requirements for all directions of all three orthogonal axes. At the other extreme, a total of nine shocks are required if each shock only satisfies the test requirements in one direction of one axis. If the required test spectrum can be satisfied simultaneously in all directions, three shock repetitions will satisfy the requirement for the test. If the requirement can only be satisfied in one direction, it is permissible to change the test set-up and impose three additional shocks to satisfy the spectrum requirement in the other direction. A suitable test shock is one that yields an SRS that equals or exceeds the required test SRS over the specified frequency range. Determine the maximax SRS for Q = 10, and at least 1/6-octave frequency intervals. The objective of the test should be to test the structural and functional integrity of the system under pyroshock in the far-field of the pyroshock device.

3.3.4 Procedure IV - Far-Field Using Electrodynamic Shaker

For Procedure IV, subject the test item to a sufficient number of suitable shocks to meet the specified test conditions. The following guidelines may be applied. For materiel that is likely to be exposed only rarely to a given pyroshock event, perform one shock for each appropriate environmental condition. For materiel that is likely to be exposed more frequently to a given pyroshock event and there is little available data to substantiate the number of pyroshocks, apply three or more shocks at each environmental condition based on the anticipated service use. The measured response will not be omni-directional. For Procedure IV it may be permissible, but highly unlikely, to simultaneously meet the test requirements along more than one axis with a single test shock configuration. Consequently, it is conceivable that a minimum of three test shock repetitions will satisfy the requirements for all directions of all three orthogonal axes. At the other extreme, a total of nine shocks are required if each shock only satisfies the test requirements in one direction of one axis. If the required test SRS can be satisfied simultaneously in all directions, three shock repetitions will satisfy the requirement for the test. If the requirement can only be satisfied in one direction, it is permissible to change the test set-up and impose three additional shocks to satisfy the SRS requirement in the other direction. A suitable test shock is one that yields an SRS that equals or exceeds the required test spectrum over the specified frequency range. Determine the maximax SRS for Q = 10, and at least 1/6-octave frequency intervals. The objective of the test should be to test the structural and functional integrity of the system under pyroshock where the low frequency structural response of the platform is the primary input to the materiel.

3.4 Supporting Assessment

It should be noted that the selected test procedure may not provide an adequate simulation of the complete environment and consequently, a supporting assessment may be necessary to compliment the test results. In the case of pyroshock this may be difficult since prediction methodology for this environment is in its infancy. What prediction methodology exists is based primarily on empirical test results with few adequate analytical models.

3.5 Isolation System

Materiel intended for use with shock isolation systems or special structural isolation configurations should normally be tested with its isolators, shock attenuation devices in position or under the special structural isolation configuration. If it is not practicable to carry out the pyroshock test with the appropriate isolators or special isolation configuration, or if the high frequency dynamic characteristic of the materiel installation are highly variable, then the test item should be tested without isolators or structural configuration at a modified severity specified in the Test Instruction. Determining the modified severity is a questionable practice, unless the materiel configuration is very basic and the scaling laws can be applied.

3.6 Sub System Testing

When identified in the Test Instruction, sub systems of the materiel may be tested separately and can be subject to different pyroshock severities. If this course of action is elected then extreme care must be exercised in properly defining the sub system boundary conditions because of the sensitivity of pyroshock levels to attachment points at sub system boundaries.

3.7 Materiel Configuration

Configure the test item for either pyroshock as would be anticipated during in-Service including particular attention to the details of the mounting of the materiel to the platform. Pyroshock response variation is particularly sensitive to the details of the materiel/platform configuration.

4 INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

4.1.1 Pretest

The following information is required to conduct a pyroshock test adequately.

a. General. Information.

- the identification of the test materiel
- the definition of the test materiel
- the type of test : development, qualification, etc.,
- the operation or non-operation of the test materiel during the test
- the packaging conditions, if applicable
- the operating checks to be performed and when, if applicable
- the control strategy
- the indication of the failure criteria

b. Specific to this method.

(1) Test system (test item/platform configuration) detailed configuration including

(a) location of the pyrotechnic device

(b) location of the materiel

(c) the structural path between the pyrotechnic device and the materiel; and any general coupling configuration of the pyrotechnic device to the platform and the platform to the materiel including the identification of structural joints

(d) distance of the closest part of the materiel to the pyrotechnic device

(2) Pyroshock environment, including

(a) type of pyrotechnic device

(b) if charge related - size of pyrotechnic device charge

(c) if charge effect - stored strain energy in primary device

(d) means of initiation of the pyrotechnic device

(e) anticipated EMI or thermal effects

(3) Duration of pyroshock if Procedure III or Procedure IV is used, or the size and distribution of the pyrotechnic device charge if Procedure I or Procedure II is used.

(4) General materiel configuration including measurement points on or near the materiel.

4.1.2 During Test

For test validation purposes, record deviations from planned or pre-test procedures or parameter levels, including any procedural anomalies that may occur.

4.1.3 Post-test

Record the following post-test information.

a. General.

Information listed previously.

b. Specific to this method.

(1) Previous test methods to which the specific test item has been

(2) Duration of each exposure or number of specific exposures.

(3) Any data measurement anomalies, e.g., instrumentation high noise levels, etc.

(4) Status of the test item for each visual examination.

(5) Test levels with supporting measurement analysis.

(6) Results of operational checks.

4.2 If Required

The number of simultaneous test materiel tolerances, if different from paragraph 5.1.

5 TEST CONDITIONS

5.1 Tolerances and Test Level Estimation

Following are guidelines for test tolerances for pyroshock for the four procedures. All tolerances are specified on the maximax acceleration SRS. Any tolerances specified on the pseudo-velocity SRS must be derived from the tolerances on the maximax acceleration SRS and be consistent with those tolerances. The test tolerances are stated in terms of single measurement tolerance. For an array of measurements defined in terms of a "zone" (reference i) a tolerance may be specified in terms of an average of the measurements within a "zone". It should be noted, however, this is in effect a relaxation of the single measurement tolerance and that individual measurements may be substantially out of tolerance while the average is within tolerance. In general, when specifying test tolerances based on averaging for more than two measurements within a zone the tolerance band should not exceed the 95/50 one-sided normal tolerance upper limit computed for the logarithmically transformed SRS estimates nor be less than the mean minus 1.5dB. Any use of “zone” tolerances and averaging must have support documentation prepared by a trained analyst. It should be noted from reference h, current aerospace practice for tolerance on the maximax SRS is given as +6/-6 dB for fn < 3 kHz and +9/-6 dB for fn > 3 kHz with at least 50% of the SRS magnitudes shall exceed the nominal test specification.

5.1.1 Procedure I

If prior measured data is available or a series of pyroshocks are performed, all acceleration maximax SRS computed with a one-tweleveth octave frequency resolution are to be within –3 dB and +6dB over a minimum of 80% of the overall frequency bandwidth from 100 Hz to 20 kHz. For the remaining 20% part of the frequency band all SRS are to be within –6dB and +9dB.

5.1.2 Procedure II

If prior measured data is available or a series of pyroshocks are performed all acceleration maximax SRS computed with a one-tweleveth octave frequency resolution are to be within –3 dB and +6dB over a minimum of 80% of the overall frequency bandwidth from 100 Hz to 20 kHz. For the remaining 20% part of the frequency band all SRS are to be within –6dB and +9dB.

5.1.3 Procedure III

If prior measured data is available or a series of pyroshocks are performed all acceleration maximax SRS computed with a one-twelveth octave frequency resolution are to be within –1.5 dB and +3dB over a minimum of 80% of the overall frequency bandwidth from 100 Hz to 10 kHz. For the remaining 20% part of the frequency band all SRS are to be within –3dB and +6dB.

5.1.4 Procedure IV

If prior measured data is available or a series of pyroshocks are performed all acceleration maximax SRS computed with a one-twelveth octave frequency resolution are to be within –1.5 dB and +3dB over a minimum of 90% of the overall frequency bandwidth from 10 Hz to 2 kHz. For the remaining 10% part of the frequency band all SRS are to be within –3dB and +6dB.

5.1.5 Sufficient Data for Test Level Estimation

When a sufficient number of representative shock spectra are available, employ an appropriate statistical technique (in general an enveloping technique) to determine the required test spectrum. Annex C of Method 503 references the appropriate statistical techniques. In general, parametric statistics can be employed if the data can be shown to satisfactorily fit an assumed underlying probability distribution. (For example, in certain standards the test levels are based upon a maximum predicted environment defined to be equal to or greater than the 95th percentile value with a confidence coefficient of at least 0.50 - this is a upper tolerance level approach. When a normal or lognormal distribution can be justified, reference i of Annex A provides a method for estimating such a test level.)

5.1.6 Insufficient Data for Test Level Estimation

When insufficient data are available for statistical analysis, use an increase over the maximum of the available spectral data to establish the required test spectrum to account for variability of the environment. The degree of increase is based upon engineering judgement and should be supported by rationale for that judgement. In these cases it is often convenient to envelope the

SRS by computing the maximax spectra over the sample spectra and proceed to add a + 6dB margin to the SRS maximax envelope.

5.2 Control

The control strategy is dependent upon the type of test and the configuration of the materiel. In general the testing is open-loop from pre-configured tests used to calibrate the test severity.

5.3 Installation Conditions of Test Materiel

5.3.1 Test Facility

Pyroshock can be applied utilising actual pyrotechnic devices in the design configuration or in a simulated configuration, conventional high acceleration amplitude/frequency test input devices, or an electrodynamic shaker. The pyroshock apparatus may incorporate a compressed gas shock tube, metal-on-metal contact, ordnance-generated pyroshock simulator, electrodynamic shaker, actual pyrotechnic device on a scale model, actual pyrotechnic device on a full scale model, or other activating types of apparatus. For Procedure I or Procedure II, references related to ordnance devices must be consulted. For Procedure III the guidelines in the method must be followed (reference g provides a source of alternative test input devices, their advantages and limitations). In this procedure it is assumed that all parts of the materiel lie in the far-field of the pyrotechnic device. Utilise the guidelines in this method (reference g of Annex A provides supplemental information for consideration for such testing). For Procedure IV, it is assumed that all parts of the materiel lie in the far-field of the pyrotechnic device and the measured or predicted data are consistent with the 2000 Hz frequency limitations of the electrodynamic shaker in addition to the acceleration amplitude limitations. It is also important to note that for large materiel, the velocity input of the shaker may exceed the velocity of the materiel under the actual pyroshock environment. For velocity sensitive materiel, this may constitute an over test. In the ensuing paragraphs the portion of the test facility responsible for delivering the pyroshock to the materiel will be termed the shock apparatus. Such shock apparatus includes the pyrotechnic shock device and the fixturing configuration in Procedure I and Procedure II, the mechanical exciter and the fixturing configuration in Procedure III, and the electrodynamic shaker and the fixturing configuration in Procedure IV.

5.3.2 Calibration

Ensure the shock apparatus is calibrated for conformance with the specified test requirement from the selected procedure. Procedure I may be used without pre-shock calibration in cases in which the configuration details are in accordance with the test plan. However, Procedure I should be used with a pre-shock calibration in cases in which the hardware is expendable and added test costs are not exorbitant, to ensure accurate test simulation for the materiel. For Procedure II, before the test item is attached to the resonating plate, it will be necessary to attach a simulated test item and obtain measured data under test conditions to be compared with the desired test response. Caution must be exercised so that the pre-test shocks do not degrade the resonating plate configuration. For Procedure III, calibration is crucial. Before the test item is attached to the shock apparatus it will be necessary to attach a simulated test item and obtain measured data under test conditions to be compared with the desired test response. For Procedure IV, utilising the SRS method with proper constraints on the effective duration of the transient, calibration is necessary. Before the test item is attached to the shock apparatus, it will be necessary to attach a simulated test item and obtain measured data under test conditions to be compared with the desired test response. For Procedure II, Procedure III and

Procedure IV, remove the calibration load and then perform the shock test on the actual test item.

5.3.3 Instrumentation

In general for pyroshock, acceleration will be the quantity measured to meet specification with care taken to ensure acceleration measurements can be made that provide meaningful data i.e., the measured data is well qualified (reference f). On occasion more sophisticated devices may be employed, e.g., laser velocimeter. In these cases give special consideration to the instrument amplitude and frequency range specifications in order to satisfy the measurement and analysis requirements.

5.3.3.1 Accelerometer

1) Transverse sensitivity of less than or equal to 5%.

2) An amplitude linearity within 10% from 5% to 100% of the peak acceleration amplitude required for testing.

3) For all pyroshock procedures a flat frequency response within $\pm$10% across the frequency range 10 - 20,000 Hz. The devices may be of the piezoelectric type or the piezoresistive type. (Experience has shown that valid pyroshock measurements within the near-field of the pyroshock device are very difficult to make.)

4) Use measurement devices compatible with the requirements and guidelines provided in the paragraphs above.

5.3.3.2 Signal conditioning

Use signal conditioning compatible with the instrumentation requirements on the materiel. In particular, filtering will be consistent with the response time history requirements. Use signal conditioning requirements compatible with the requirements and guidelines provided in the paragraphs above. In particular use extreme care in filtering the acceleration signals either (1) directly at the attachment point, i.e., mechanical filtering to reduce the very high frequencies associated with the pyroshock, or (2) at the amplifier output. The signal into the amplifier should never be filtered for fear of filtering bad measurement data and the inability to detect the bad measurement data. The signal from the signal conditioning must be anti-alias filtered before digitising.

5.3.4 Data Analysis

5.3.4.1 Digitising the analog voltage signal will not alias more than a 5 percent measurement error into the frequency band of interest (100 Hz to 20 kHz).

5.3.4.2 Filters that are used to satisfy the data digitisation requirement shall have linear phase-shift characteristics.

5.3.4.3 Filters that are used to satisfy the data digitisation requirement shall have a pass band flatness within one dB across the frequency range specified for the accelerometer (see paragraph 5.3.3).

5.3.4.4 Analysis procedures will be in accordance with those requirements and guidelines provided in the paragraphs of this method (supplemental information can be found in reference f of Annex A). In particular the pyroshock acceleration amplitude time histories will be qualified according to the procedures provided in the paragraphs of this method. Each amplitude time history will be integrated to detect any anomalies in the measurement system e.g., cable breakage, slew rate of amplifier exceeded, data clipped, unexplained accelerometer offset, etc. The integrated amplitude time histories will be compared against criteria given in the paragraphs of this method. For Procedure I and Procedure II to detect emission from extraneous sources, configure an accelerometer without sensing element and process its response in the same manner as for the other accelerometer measurement responses. If this accelerometer exhibits any character other than very low level noise, consider the acceleration measurements to be contaminated by an unknown noise source.

5.3.5 Test Set-up

5.3.5.1 Procedure I

5.3.5.2 In this procedure the materiel is tested on the actual overall configuration. For installation insure the in-Service mounting conditions are maintained.

5.3.5.3 Procedure II

In this procedure mount the materiel on the flat plate (or other suitable simulation device) in either an isolated or an un-isolated configuration dependent upon the in-Service condition.

5.3.5.4 Procedure III

In this procedure follow test instruction procedures for installing materiel for a shock test. Details of the installation procedures will depend upon the test device configuration.

5.3.5.5 Procedure IV

In this procedure follow test instruction procedures for installing materiel for a shock test on an electrodynamic shaker.

5.4 Effects of Gravity

Because of the potentially high acceleration levels for pyroshock, gravity has no effect on the test configuration or analysis of the test data. Only in cases in which the materiel itself is sensitive to gravity and the operation of the materiel depends upon the direction of gravity relative to the materiel orientation should the effects of gravity be considered.

5.5 Preparation for Test

5.5.1 Preliminary steps

Prior to initiating any testing, review pre-test information in the test instruction to determine test details (e.g., procedures, test item configuration, pyroshock levels, number of pyroshocks):

a Choose the appropriate test procedure.

b Determine the appropriate pyroshock levels for the test prior to calibration for Procedure II, Procedure III and Procedure IV from previously processed data (if available).

c Ensure the pyroshock signal conditioning and recording device has adequate amplitude range and frequency bandwidth. It may be difficult to estimate a peak signal and range the instrumentation appropriately. In general there is no data recovery from a clipped signal, however for overranged signal conditioning, it is usually possible to get out meaningful results for a signal 20 dB above the noise floor of the measurement system. In some cases, redundant measurements may be appropriate, one measurement being overranged and one measurement ranged at the best estimate for the peak signal. The frequency bandwidth of most recording devices is usually readily available, but one must make sure that device input filtering does not limit the signal frequency bandwidth.

5.5.2 Pre-test checkout

All items require a pre-test checkout at standard ambient conditions to provide baseline data. Conduct the checkout as follows:

Step 1. Conduct a complete visual examination of the test item with special attention to any micro electronic circuitry areas. Pay particular attention to its platform mounting configuration and potential stress wave transmission paths.

Step 2. Document the results for compliance with General Requirements.

Step 3. Where applicable, install the test item in its test fixture.

Step 4. Conduct an operational checkout in accordance with the approved test plan along with simple tests for ensuring the measurement system is responding properly.

Step 5. Document the results for compliance with General Requirements.

Step 6. If the test item operates satisfactorily, proceed to the first test. If not, resolve the problem and restart at Step 1.

Step 7. Remove the test item and proceed with the calibration (except in the case of Procedure I for no pre-shock calibration).

5.6 Procedures

The following procedures provide the basis for collecting the necessary information concerning the platform and test item under pyroshock.

5.6.1 Procedure I - Near-Field with Actual Configuration.

Step 1. Following the guidance of paragraphs of this test method (based upon supplemental information provided in references in Annex A), select test conditions and mount (1) the test item if there will be no calibration for actual materiel configuration used in this procedure or (2) a dynamically similar test item if there is to be calibration prior to testing. Select accelerometers and analysis techniques, which meet the criteria, outlined in previous paragraphs of this method (with supplemental information contained in reference f in Annex A).

Step 2. Perform a functional check on the test item.

Step 3. Subject the test item (in its operational mode) to the test transient by way of the pyrotechnic device.

Step 4. Record necessary data that show the shock transients met or exceeded desired test levels. This includes test set-up photos, test logs, and plots of actual shock transients. For shock isolated assemblies within the test item, make measurements and/or inspections to assure these assemblies did attenuate the pyroshock.

Step 5. Perform the functional check on the test item. Record performance data.

Step 6. If a dynamically similar test item is used to calibrate the test set-up, repeat steps 3, 4 and 5 a minimum of three times for statistical confidence. If the required test tolerances have been met, replace the substitute test item with the actual test item and repeat steps 3, 4 and 5 as specified in the Test instruction.

Step 7. Document the test series.

5.6.2 Procedure II - Near-Field with Simulated Configuration

Step 1. Following the guidance provided in this method (with supplemental information in reference g of Annex A), select test conditions and calibrate the shock apparatus as follows:

a. Select accelerometers and analysis techniques, which meet the criteria, outlined in previous paragraphs of this method (with supplemental information contained in reference f in Annex A).

b. Mount the calibration load (the actual test item, a rejected test item, or a rigid dummy mass) to the test apparatus in a manner similar to that of the actual test item. If the test item is normally mounted on shock isolators to attenuate the pyroshock, ensure the isolators are functional during the test.

c. Perform calibration shocks until two consecutive shock applications to the calibration load that produce waveforms which, when processed with SRS algorithm, meet or exceed the desired test conditions, for at least one direction of one axis.

d. Remove the calibrating load and install the actual test item on the shock apparatus paying close attention to mounting details.

Step 2. Perform a functional check on the test item.

Step 3. Subject the test item (in its operational mode) to the test pyroshock.

Step 4. Record necessary data that show the shock transients met or exceeded desired test levels. If requirements are given in terms of more than one axis, examine responses in the other axes to ensure the test specification has been met. Include test set-up photos, test logs, and photos of actual shock transients. For shock isolated assemblies within the test item, make measurements and/or inspections to assure the isolators attenuated the pyroshock.

Step 5. Perform the functional check on the test item. Record performance data.

Step 6. If a dynamically similar test item is used to calibrate the test set-up, repeat steps 3, 4 and 5 a minimum of three times (for each of the three axis) for statistical confidence. If the required test tolerances have been met, replace the substitute test item with the actual test item and repeat steps 3, 4 and 5 (for each of the three axis) as specified in the Test instruction.

Step 7. Document the test series.

5.6.3 Procedure III - Far-Field Using Mechanical Test Device.

Step 1. Following the guidance provided in this method (with supplemental information in reference g of Annex A), select test conditions and calibrate the shock apparatus as follows:

a. Select accelerometers and analysis techniques, which meet the criteria, outlined in previous paragraphs of this method (with supplemental information contained in reference f in Annex A).

b. Mount the calibration load (the actual test item, a rejected item, or a rigid dummy mass) to the test apparatus in a manner similar to that of the actual materiel. If the materiel is normally mounted on shock isolators to attenuate the pyroshock, ensure the isolators are functional during the test.

c. Perform calibration shocks until two consecutive shock applications to the calibration load that produce waveforms which, when processed with SRS algorithm, meet or exceed derived test conditions for at least one direction of one axis.

d. Remove the calibrating load and install the actual test item on the shock apparatus paying close attention to mounting details.

Step 2. Perform a functional check of the test item.

Step 3. Subject the test item (in its operational mode) to the test pyroshock.

Step 4. Record necessary data that show the shock transients met or exceeded desired test levels. If requirements are given in terms of more than one axis, examine responses in the other axes to ensure the test specification has been met. Include test set-up photos, test logs and photos of actual shock transients. For shock isolated assemblies within the test item, make measurements and/or inspections to assure the isolators attenuated the pyroshock.

Step 5. Perform the functional check on the test item. Record performance data.

Step 6. If a dynamically similar test item is used to calibrate the test set-up, repeat steps 3, 4 and 5 a minimum of three times for statistical confidence. If the required test tolerances have been met, replace the substitute test item with the actual test item and repeat steps 3, 4 and 5 as specified in the Test instruction.

Step 7. Document the test series.

5.6.4 Procedure IV - Far-Field Using Electrodynamic Shaker.

Step 1. Following the guidance provided in this method (with supplemental information in references of Annex A), select test conditions and calibrate the shock apparatus as follows:

a. Select accelerometers and analysis techniques, which meet the criteria, outlined in previous paragraphs of this method (with supplemental information contained in reference f in Annex A).

b. Mount the calibration load (the actual test item, a rejected item, or a rigid dummy mass) to the electrodynamic shaker in a manner similar to that of the actual materiel. If the materiel is normally mounted on shock isolators to attenuate the pyroshock, ensure the isolators are functional during the test.

c. Develop the SRS wavelet or damped sine compensated amplitude time history based on the required test SRS.

d. Perform calibration shocks until two consecutive shock applications to the calibration load that produce waveforms which, when processed with SRS algorithm, meet or exceed derived test conditions for at least one direction of one axis.

e. Remove the calibrating load and install the actual test item on the electrodynamic shaker paying close attention to mounting details.

Step 2. Perform a functional check on the test item.

Step 3. Subject the test item (in its operational mode) to the test electrodynamic pyroshock simulation.

Step 4. Record necessary data that show the shock transients met or exceeded desired test levels. If requirements are given in terms of more than one axis, examine responses in the other axes to ensure the test specification has been met. Include test set-up photos, test logs, and photos of actual shock transients. For shock isolated assemblies within the test item, make measurements and/or inspections to assure the isolators attenuated the pyroshock.

Step 5. Perform the functional check on the test item. Record performance data.

Step 6. If a dynamically similar test item is used to calibrate the test set-up, repeat steps 3, 4 and 5 a minimum of three times for statistical confidence. If the required test tolerances have been met, replace the substitute test item with the actual test item and repeat steps 3, 4 and 5 as specified in the Test instruction.

Step 7. Document the test series.

6 FAILURE CRITERIA

In addition to the guidance provided above, the following information is provided to assist in the evaluation of the test results. Analyse any failure of a test item to meet the requirements of the system specifications, and consider related information such as follows.

6.1 Procedure I - Near-Field with Actual Configuration

Carefully evaluate any failure in the structural configuration of the test item, e.g., mounts or tiedowns, that may not directly impact failure of the functioning of the materiel but that would lead to failure in its service environment conditions. Carefully examine any failures as a result of EMI emission.

6.2 Procedure II - Near-Field with Simulated Configuration

Carefully evaluate any failure in the structural configuration of the test item, e.g., mounts or tiedowns, that may not directly impact failure of the functioning of the materiel but that would lead to failure in its service environment conditions. Carefully examine any failures as a result of EMI emission.

6.3 Procedure III - Far-Field Using Mechanical Test Device

The mechanical shock simulation will, in general, provide a more severe low frequency environment (comparatively large velocity and displacement) than the actual pyroshock event and, hence, any structural failures may be more akin to those found in the SRS prescribed shock tests described in Method 503. Clearly identify structural failures that may be due solely to over test in the low frequency environment.

6.4 Procedure IV - Far-Field Using Electrodynamic Shaker

The mechanical shock simulation will, in general, provide a more severe low frequency environment (comparatively large velocity) than the actual pyroshock event and, hence, any structural failures may be more akin to those found in the SRS prescribed shock tests described in Method 503. Clearly identify structural failures that may be due solely to over test in the low frequency environment.

ANNEX A

TECHNICAL GUIDANCE

1 SCOPE

1.1 This annex is designed to provided technical guidance on the general considerations and terminology given to pyroshock testing within the last few years that is supported by the references in this annex.

1.2 General Considerations - Terminology

1.2.1 Single Measured Environments

In general, response acceleration will be the experimental variable of measurement for pyroshock. This choice of measurement variable does not preclude other variables of measurement such as velocity, displacement or strain from being measured and processed in an analogous manner, as long as the interpretation, capabilities and limitations of the measurement variable are clear. Particular attention must be given to the high frequency environment generated by the pyrotechnic device and the capabilities of the measurement system to faithfully record the materiel responses. Reference f in Annex A details the trade-off amongst pyroshock measurement procedures.

The guidelines in reference f should be implemented. The terms that follow will be helpful in the discussion relative to analysis of response measurements from pyroshock testing. To facilitate the definition of the terms, each of the terms is illustrated for a typical pyroshock measurement. Figure 415-1 provides an acceleration amplitude time history plot of a measured far-field pyroshock with the instrumentation noise floor displayed before the pyroshock, the pyroshock and the subsequent post-pyroshock noise floor. It is important to provide measurement data including both the pre-pyroshock noise measurement and the post-pyroshock combined noise and low level residual structure response. The first and last vertical lines represent the equal duration pre-pyroshock, pyroshock and post-pyroshock time intervals selected for analysis. The pre-pyroshock time interval contains the instrumentation system noise floor and serves as a measurement signal reference level. The pyroshock time interval includes all the significant response energy of the event. The post-pyroshock time interval is of equal duration to the pre-pyroshock time interval and contains the measurement system noise in addition to some of the pyroshock residual noise inconsequential to the response energy in the pyroshock. In some cases in which the pre-pyroshock and the post-pyroshock amplitude levels are substantial compared to the pyroshock (the pyroshock has been mitigated and/or the measurement system noise is high), the identification of the pyroshock may need critical engineering judgement relative to the start and the termination of the pyroshock event). In any case, analysis of pre-pyroshock and post-pyroshock measurement information in conjunction with the pyroshock measurement information is essential. Validate all data collected from a pyroshock. Reference f provides some guidelines for this. Perhaps one of the simplest and most sensitive criteria for validation is an integration of the signal time history after removing any small residual offset. If the resulting integrated signal has zero crossings and does not appear to go unbounded, the pyroshock has passed the first validation test. Figure 415-2 provides the velocity plot for the pyroshock in Figure 415-1.

(1) Effective Transient Duration: For a pyroshock, the "effective transient duration", $T_{e,}$ is the minimum length of time which contains all significant amplitude time history magnitudes beginning at the noise floor of the instrumentation system just prior to the initial most significant measurement, and proceeding to the point that the amplitude time history is a combination of measurement noise and substantially decayed structural response.

An experienced analyst is required to determine the pertinent measurement information to define the pyroshock event. The longer the duration the pyroshock, the more low frequency information is preserved which may be important for far-field test considerations. For near-field test considerations the effective transient duration will much shorter because of the higher ranging of the measurement system. The amplitude criterion requires that the amplitude of the post-pyroshock amplitude time history envelope be no more than 12 dB above the noise floor of the measurement system depicted in the pre-pyroshock amplitude time history. From Figure 415-1 there appears to be at least two logical times at which the pyroshock might be terminated. The first time is immediately after the end of the high frequency information - the second vertical dashed line in Figure 415-1 at approximately 3.5 milliseconds after the beginning of the pyroshock. The second time is given by the third vertical line in Figure 415-1, some 6.6 milliseconds after the beginning of the pyroshock and after some of the apparent low frequency structural response has been attenuated - the third vertical dashed line in Figure 415-1. These judgements based on examination of the amplitude time history utilised an amplitude criterion and a frequency criterion. Figure 415-3 contains a plot of amplitude of the absolute value of the pyroshock in dB versus time. This figure illustrates the difficulty in coming up with precise criteria for determining the effective duration of a pyroshock. The initial noise floor level is never obtained in the record. Figure 415-1 illustrates the difference between processing the two different pyroshocks in Figure 415-1, with the SRS, i.e., the short duration pyroshock and the long duration pyroshock. It is clear that the only significant difference is near 100 Hz. The magnitude of the SRS at lower natural frequencies can be quite sensitive to the effective transient duration, whereas the SRS at higher natural frequencies is generally insensitive to the effective transient duration.

(2) Shock Response Spectrum Analysis: Reference m defines the absolute acceleration maximax Shock Response Spectrum (SRS) and provides examples of the SRS computed for classical pulses. The SRS value at a given undamped natural oscillator frequency, fn, is defined to be the absolute value of the maximum of the positive and negative acceleration responses of a mass for a given base input to a damped single degree of freedom system. The base input is the measured shock over a specified duration (the specified duration should be the effective duration). For processing of pyroshock shock response data, the absolute acceleration maximax SRS has become the primary analysis descriptor. In this measurement description of the pyroshock, the maximax absolute acceleration values are plotted on the ordinate with the undamped natural frequency of the single degree of freedom system with base input plotted along the abscissa.

A more complete description of the pyroshock (and potentially more useful for pyroshock damage comparison in the far-field) can be obtained by determining the pseudo-velocity response spectrum and plotting this on four-coordinate paper where, in pairs of orthogonal axes, the pseudo-velocity response spectrum is represented by the ordinate with the undamped natural frequency being the abscissa and the maximax absolute acceleration along with the pseudo-displacement plotted in a pair of orthogonal axes, all plots having the same abscissa (reference m). The pseudo-velocity at a particular oscillator undamped natural frequency is thought to be more representative of the damage potential for a shock since it correlates with stress and strain in the elements of a single degree of freedom system (reference b). The pseudo-velocity response spectrum can be computed either by (1) dividing the maximax absolute acceleration response spectrum by the undamped natural frequency of the single degree of freedom system, or (2) multiplying the relative displacement by the undamped natural frequency of the single degree of freedom system. Both these means of computation provide essentially the same spectra except possibly in the lower frequency region, in which case the second method of computation is more basic to the definition of the pseudo-velocity response spectrum.

Figure 415-5 provides the estimate of the maximax absolute acceleration SRS for the record pyroshock record in Figure 415-1, and Figure 415-6 provides the estimate of the pseudo-velocity, pseudo-displacement and maximax absolute acceleration for this record on four-coordinate paper. In general, compute the SRS over the pyroshock event duration and over duration measurement for the pre-pyroshock and the post-pyroshock events with twelfth octave spacing and a Q = 10 (Q=10 corresponds to a single degree of freedom system with 5% critical damping). Figure 415-5 also provides estimates of the maximax absolute acceleration SRS for the pre-pyroshock and the post-pyroshock. Figure 415-6 provides estimates of the pseudo-velocity response spectrum for the pre-pyroshock and the post-pyroshock. If the testing is to be used for laboratory simulation, use a second Q value of 50 Q=50 corresponds to a single degree of freedom system with 1% critical damping) in the processing. It is recommended that the maximax absolute acceleration SRS be the primary method of display for the pyroshock, with the pseudo-velocity response spectrum as the secondary method of display and useful in cases in which it is desirable to be able to correlate damage of simple systems with the pyroshock.

(3) Energy Spectral Density: Reference n of Annex A defines the Energy Spectral Density (ESD) estimate for a pyroshock of duration T. In this description, the properly scaled magnitude of the Fourier Transform of the total pyroshock is computed at a uniform set of frequencies and displayed as a two-dimensional plot of amplitude versus frequency. The amplitude units are (units**2-sec)/Hertz. In determining the ESD estimate, it is important that, if the Fast Fourier Transform is used, the block size is selected such that all of the pyroshock event is contained within the block but excessive noise beyond the duration of the transient is removed by zero-padding the Fourier Transform block. The ESD description is useful for comparing the distribution of energy within the frequency band amongst several pyroshocks. However, if adjacent frequency components are not averaged, the percentage of normalised random error in the ordinate is 100%. By averaging n adjacent ordinates, the percentage of normalised random error decreases as $1/\sqrt{(n)}$ with a decreased frequency resolution. Computation of the ESD estimates for the pre-pyroshock and the post-pyroshock provide useful information relative to the distinct frequency character of the pyroshock as compared to the frequency character

of the pre-pyroshock noise and the post-pyroshock combination noise and structural response.

Figure 415-7 provides ESD estimates for the pyroshock and the pre-pyroshock and post-pyroshock events in Figure 415-1, respectively.

(4) Fourier Spectra: Reference n in Annex A defines the Fourier Spectra (FS) estimate for a pyroshock of duration T. In this description, the properly scaled square root of the magnitude of the Fourier Transform of the total pyroshock is computed at a uniform set of frequencies and displayed as a two-dimensional plot of amplitude versus frequency. The amplitude units are (units-sec). In determining the FS estimate, as in the case of the ESD estimate, it is important that if the Fast Fourier Transform is used, that the block size is picked such that all of the transient is contained within the block but excessive noise beyond the duration of the transient is removed by zero-padding the Fourier Transform block. This description is useful for noting outstanding frequency components within the overall frequency band amongst pyroshocks. If adjacent frequency components are not averaged, the percentage normalised random error in the ordinate is 100%. By averaging n adjacent ordinates, the percentage of normalised random error decreases as $1/\sqrt{(n)}$ with a decreased frequency resolution. Computation of the FS estimates for the pre-pyroshock and the post-pyroshock provide useful information relative to the distinct frequency character of the pyroshock as compared to the frequency character of the pre-pyroshock noise and the post-pyroshock combination noise and structural response.

Figure 415-8 provides FS estimates for the pyroshock and the pre-pyroshock and post-pyroshock events in Figure 415-1, respectively.

(5) Other Methods: Over the past few years, at least two other techniques potentially useful in processing pyroshock data have been suggested. Reference j in Annex A describes the utilisation of time domain or temporal moments for comparing the characteristics of the pyroshock over different frequency bands. The usefulness of this technique resides in the fact that if the pyroshock can be represented by a simple nonstationary product model, the time domain moments must be constant over selected filter bandwidths. Thus the pyroshock can be characterised by a model with potential usefulness for stochastic simulation. Reference k in Annex A explores this reasoning for mechanical shock. It has been suggested (reference l in Annex A) that "wavelet" processing may be useful for pyroshock description, particularly if a pyroshock contains information at intervals of time over the duration of the shock at different time scales, i.e., different frequencies. It is likely that this form of processing may become more prevalent in the future as the level of examination of transients becomes more sophisticated and if "wavelet" processing is shown to be more useful for description of phenomenon with substantial randomness.

1.2.2 Combination of Measurements

In general, for pyroshock tests a single response record is obtained. At times it may be convenient or even necessary to combine equivalent processed responses in some appropriate statistical manner. Reference i Annex A and Method 503, Annex C of this standard discuss some options in statistically summarising processed results from a series of tests. In general, processed results, either from the SRS, ESD or FS are logarithmically transformed in order to provide estimates that are more normally distributed. This is important since often very little data are available from a test series, and the probability distribution of the untransformed estimates cannot be considered to be normally distributed. In all cases, the combination of processed results will fall under the category of small sample statistics and needs to be considered with care utilising parametric or less powerful nonparametric methods of statistical analysis. Annex C of Method 503 addresses some appropriate techniques for the statistical combination of processed test results from a limited number of tests.

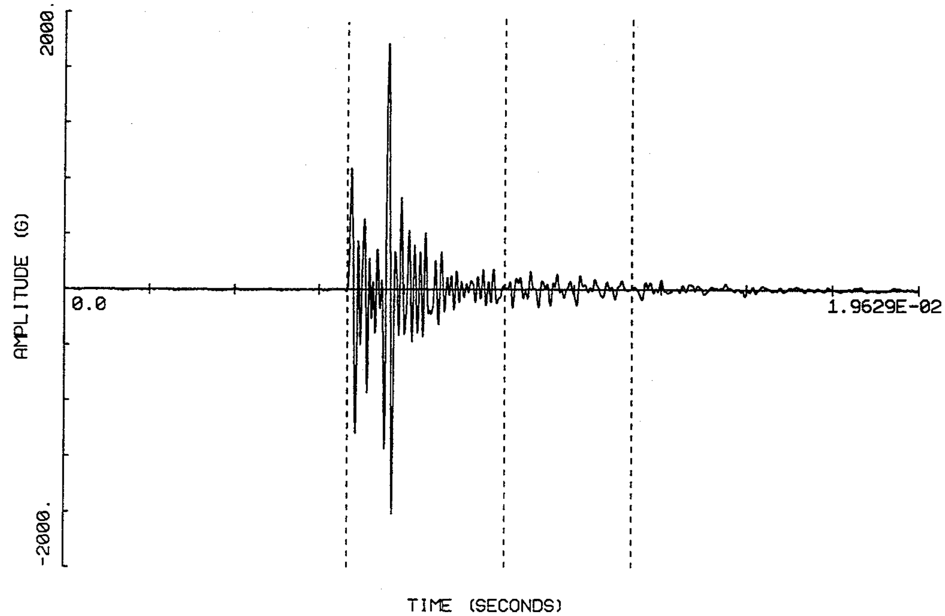

Figure 415-1. Total event pyroshock amplitude time history.

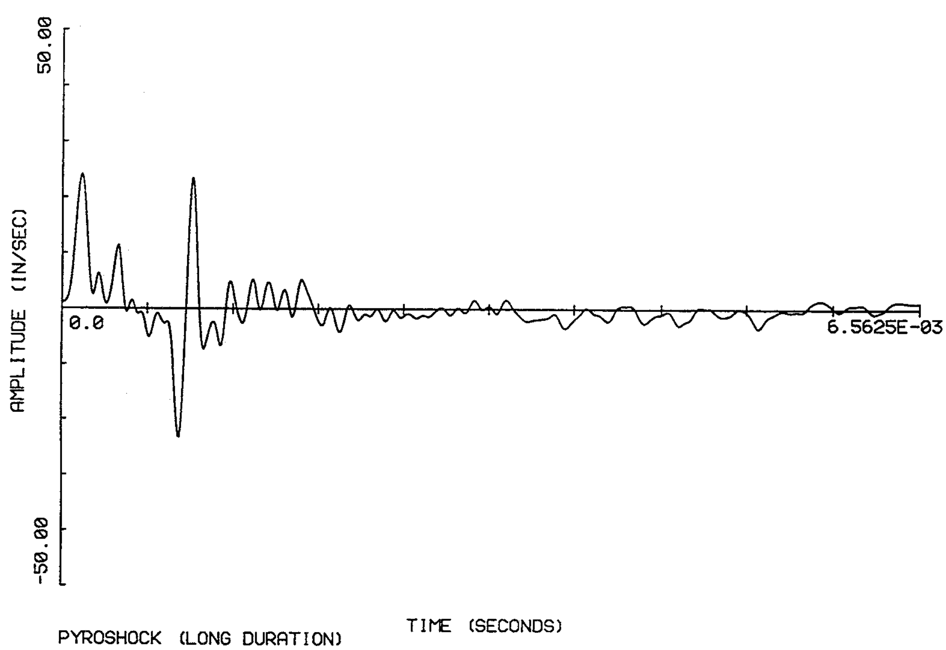

Figure 415-2. Pyroshock velocity amplitude time history.

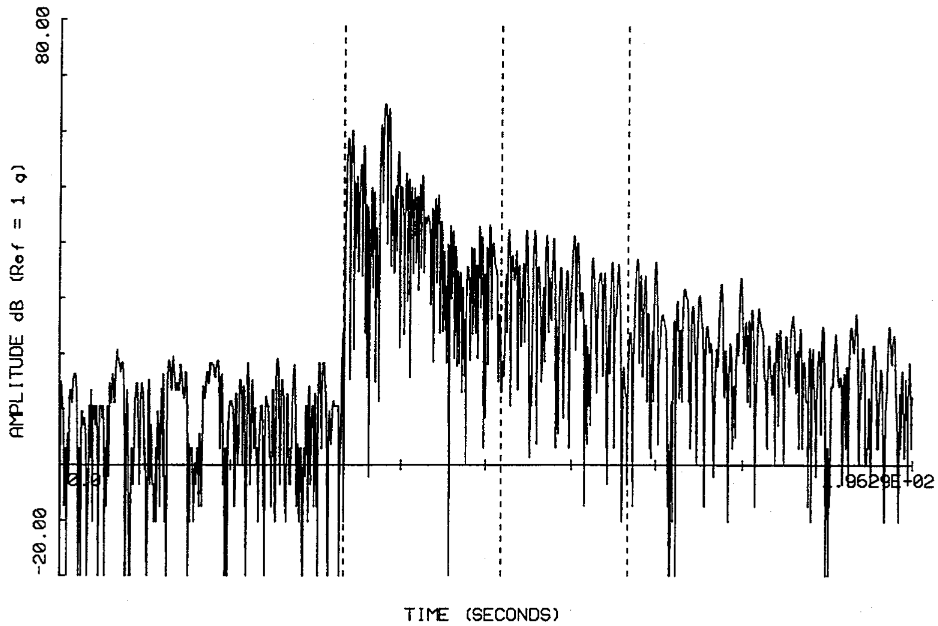

Figure 415-3. Magnitude amplitude time history.

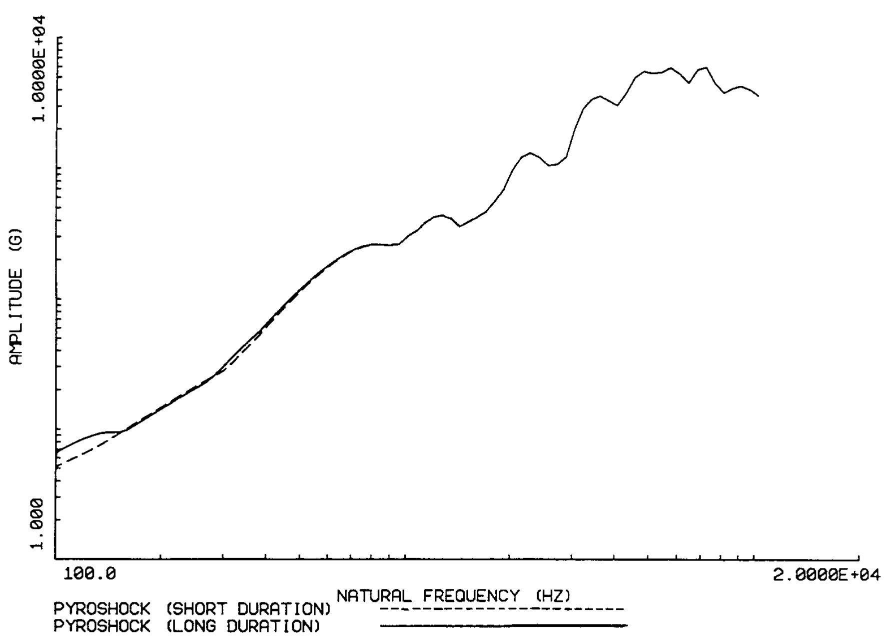

Figure 415-4. Acceleration maximax SRS.

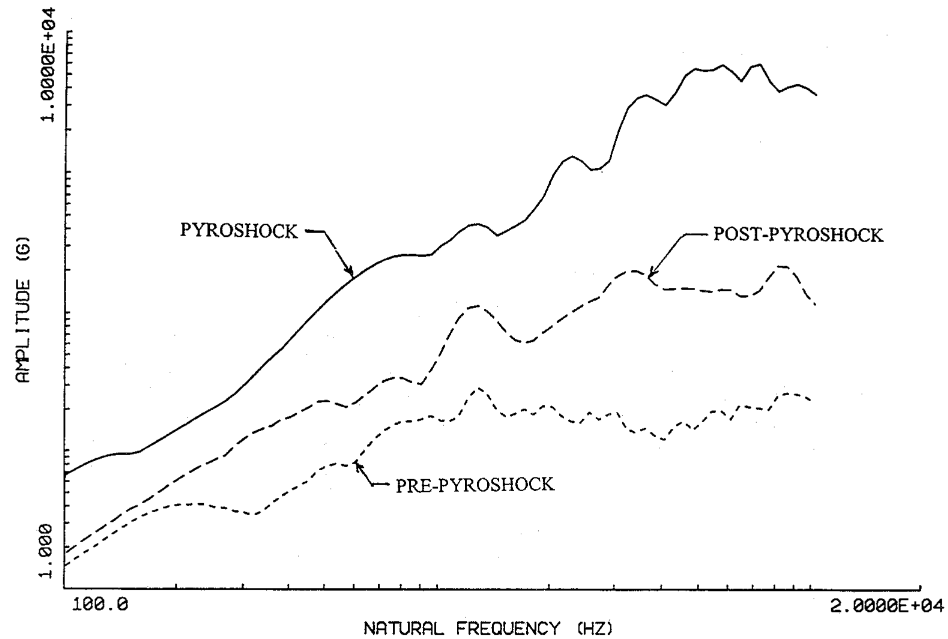

Figure 415-5. Acceleration maximax SRS: - total shock event.

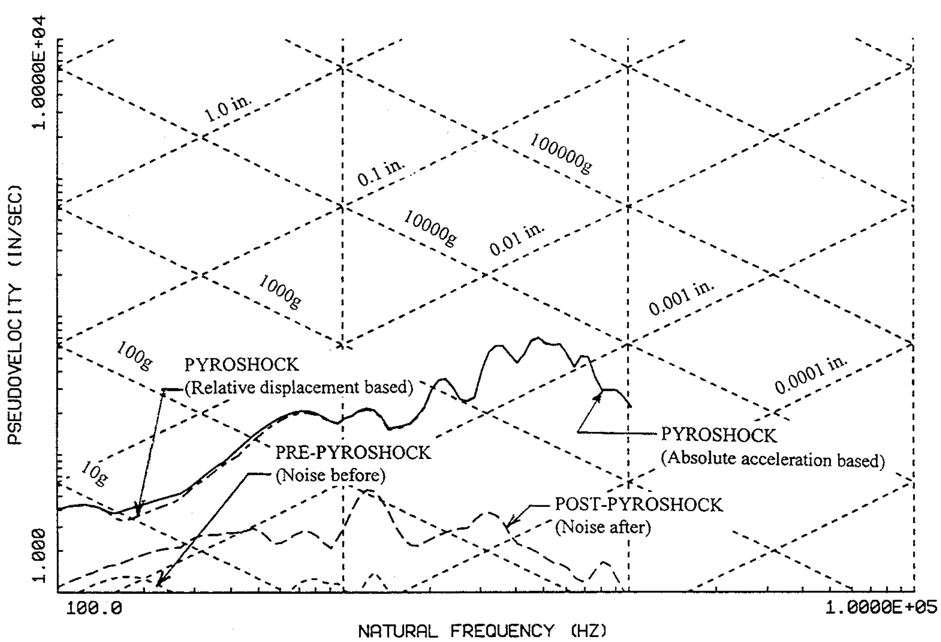

Figure 415-6. Pseudovelocity response spectrum.

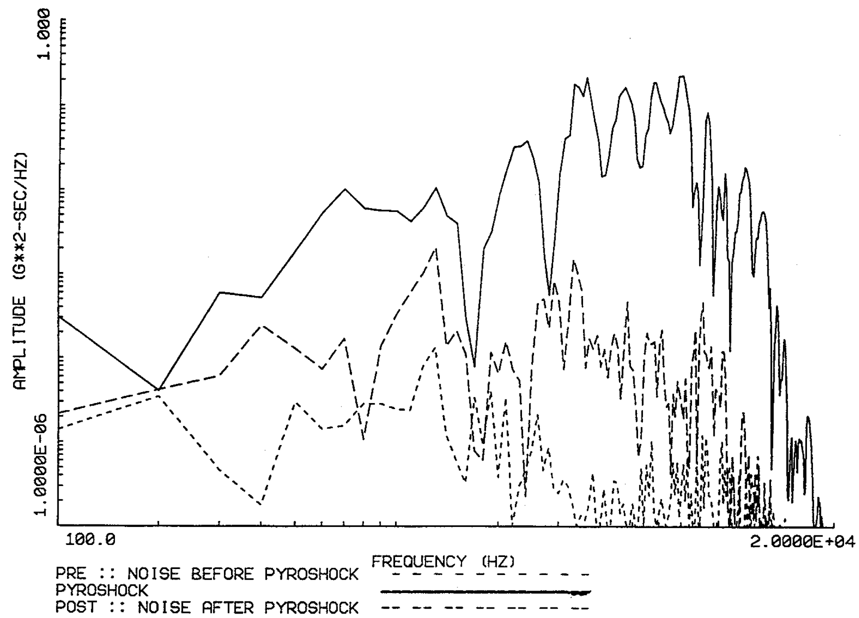

Figure 415-7. Acceleration energy spectral density estimate.

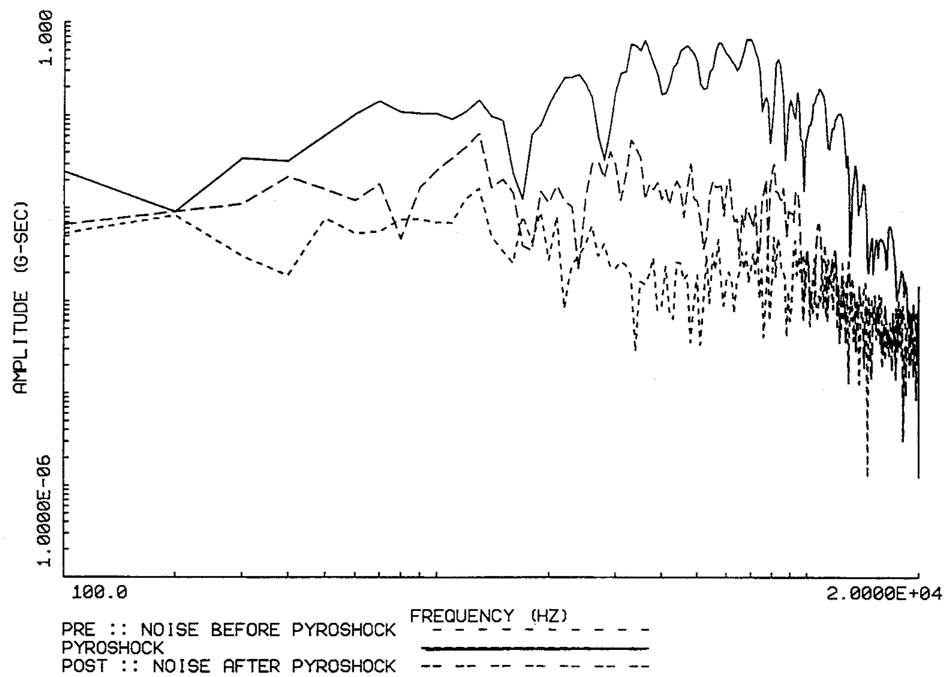

Figure 415-8. Acceleration Fourier transform estimate.

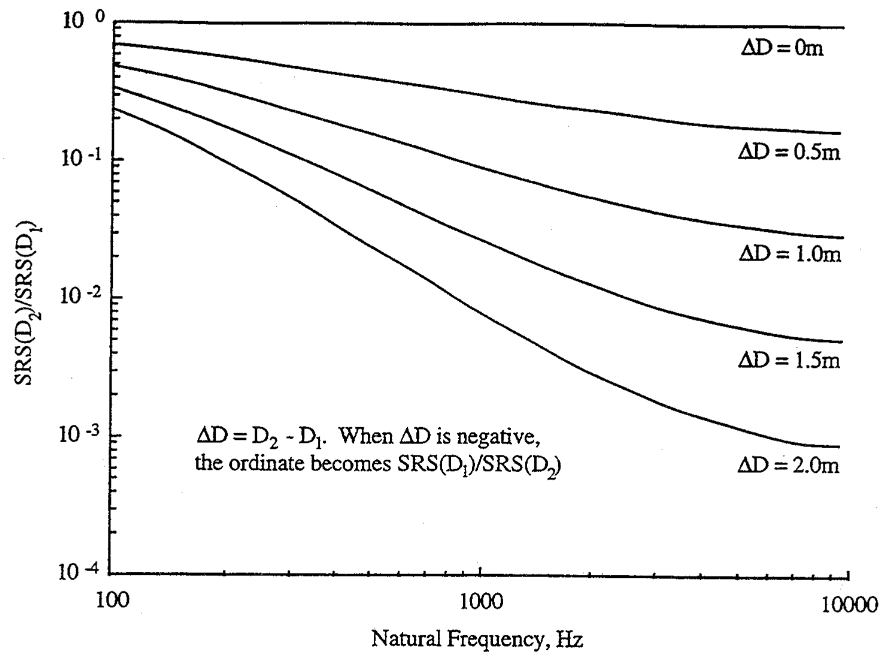

Figure 415-9. Correction of shock response spectrum for distance from pyrotechnic source.

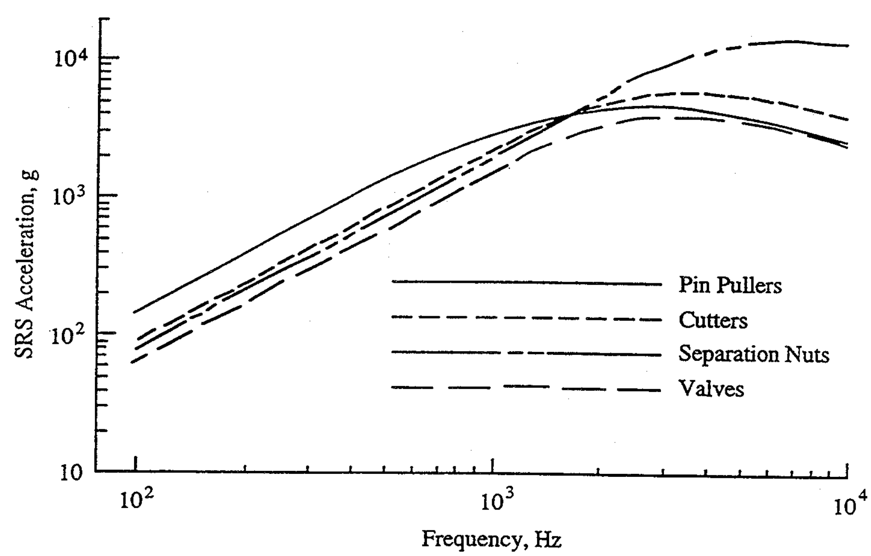

Figure 415-10. Shock response spectra for various point source pyrotechnic devices.

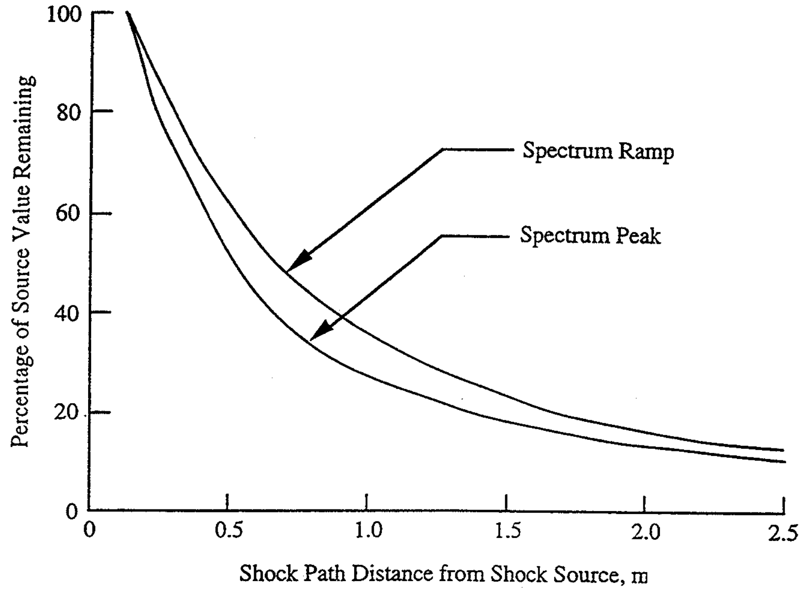

Figure 415-11. Shock response spectrum versus distance from pyrotechnic source.

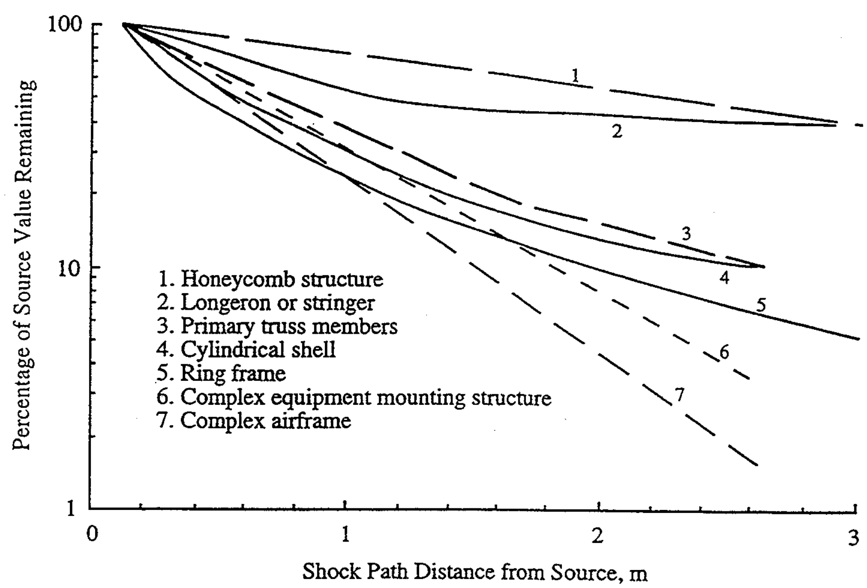

Figure 415-12. Peak pyroshock time history response versus distance from pyrotechnic source.

2 REFERENCES AND RELATED DOCUMENTS

Included below are references used in the text to define terminology and provide information on techniques used in pyroshock testing.

a. Harris, Cyril M., ed. Shock and Vibration Handbook, 3rd Edition, NY, McGraw-Hill, 1988.

b. Gaberson, H. A. and R. H. Chalmers. Model Velocity as a Criterion of Shock Severity, Shock and Vibration Bulletin 40, Pt. 2, (1969) 31-49.

c. ANSI/ASTM D3332-77, Standard Methods for Fragility of Products Using Machines. 1977.

d. Gaberson, H. A. and R. H. Chalmers. Reasons for Presenting Shock Spectra with Velocity as the Ordinate, Proc. 66th Shock and Vibration Symp., Vol. II, pp 181-191, Oct/Nov. 1995.

e. Piersol, A.G., Analysis of Harpoon Missile Structural Response to Aircraft Launches, Landings and Captive Flight and Gunfire. Naval Weapons Center Report #NWC TP 58890. January 1977.

f. Handbook for Dynamic Data Acquisition and Analysis, IES-RP-DTE012.1, Institute of Environmental Sciences, 940 East Northwest Highway, Mount Prospect, Illinois 60056

g. Bateman, V. I. and N. T. Davie, Recommended Practice for Pyroshock, IES Proceedings of the 42nd ATM 1995, Institute of Environmental Sciences, Mount Prospect, Illinois.

h. Himelblau, Harry, Dennis L. Kern and Allan G. Piersol, The Proposed NASA Pyroshock Test Criteria Standard - Part I & Part 2, Proc of the 67th Shock and Vibration Symposium, Vol 1, Nov 1996.

i. Piersol, Allan G., Procedures to Compute Maximum Structural Responses from Predictions or Measurements at Selected Points, Shock and Vibration Journal, Vol. 3, Issue 3, 1996, pp 211-221.

j. Smallwood, David O., Characterization and simulation of Transient Vibrations Using Band Limited Temporal Moments, Shock and Vibration Journal, Volume 1, Issue 6, 1994, pp 507-527.

k. Merritt, Ronald G., A Note on Transient Vibration Model Detection, IES Proceedings of the 42nd ATM 1995, Institute of Environmental Sciences, Mount Prospect, Illinois.

l. Newland, D. E., An Introduction to Random Vibrations, Spectral & Wavelet Analysis, John Wiley & Sons, Inc., New York 1995.

m. Kelly, Ronald D. and George Richman, Principles and Techniques of Shock Data Analysis, The Shock and Vibration Information Center, SVM-5, United States Department of Defense.

n. Himelblau, Harry, Dennis L. Kern, Allan G. Piersol, Sheldon Rubin, Guidelines for Dynamic Environmental Criteria (Preliminary Draft), Jet Propulsion Laboratory, California Institute of Technology, March 1997

o. Zimmerman, Roger M., Section 32, VII. Shock Test Techniques, 3) Pyroshock-Bibliography, Experimental Mechanics Division I, Sandia National Laboratories, Albuquerque, NM, April 19,1991

p. Barrett, S., The Development of Pyro Shock Test Requirements for Viking Lander Capsule Components, Proc. 21st ATM, Inst. Envir. SC., pp 5-10, Apr. 1975

q. Kacena, W. J., McGrath, M. B., and Rader, W. P., Aerospace Systems Pyrotechnic Shock Data, NASA CR-116437, -116450, -116401, -116402, -116403, -116406, and -116019, Vol. I-VII, 1970.

METHOD 416

RAIL IMPACT

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METHOD 416

RAIL IMPACT

1 SCOPE

1.1 Purpose

The purpose of this test method is to replicate the railroad car impact conditions that occur during rail shipment, incurred by systems, subsystems and units hereafter called materiel, and their tiedown arrangements during the specified logistic conditions.

Rail impacts tests are also conducted to subject large materiel to specified shocks longitudinal and/or transverse to the direction of travel to demonstrate their strength. This will be described as Test Procedure II.

1.2 Application

Test Procedure I is applicable where a materiel is required to demonstrate its adequacy to resist the specified railroad car impact environment without unacceptable degradation of its functional and/or structural performance. This test is mandatory for materiel to be transported by rail in the US.

Test Procedure II is applicable for the generation of a low-level, long duration shock on large test items, and is a requirement of the European Railway Administration.

Test Procedure III is a laboratory simulation applicable to items fitted onto or transported by railway vehicles.

AECTPs 100 and 200 provide additional guidance on the selection of a test procedure for specific rail impact environment.

1.3 Limitations

This method is not intended for small individual packages that would normally be shipped mounted on a pallet, nor crash conditions.

2 GUIDANCE

2.1 Effect of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel are exposed to the rail impact environment.

(1) Loosening of tiedown straps

(2) Failure of attachments

(3) Shifting of materiel on the rail car

(4) Failure of materiel

2.2 Use of Measured Data

Measured data is not applicable to this test.

2.3 Choice of Test procedures

Procedure I is mandatory for test items shipped by rail within the US.

Procedure II is for shock test only and is a requirement of the European railway Adminis tration.

Procedure III is a laboratory shock test used to simulate the rail impact environment and is based on levels found in Ref (1) and (2).

2.4 Sequence

The order of the rail impact testing will be determined by the responsible authority.

3 SEVERITIES

Test conditions are specified in paragraph 5.3.

4 INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- the identification of the test item
- the definition of the test item
- the definition of test severity
- tiedown conditions
- axis and senses in which the impact is applied to the test item
- details required to perform the test
- speed measurement
- the indication of the failure criteria

4.2 If required

- tolerances, if different from para. 5.1.,
- Tolerances on acceleration and pulse widths (procedure II)

5 TEST CONDITIONS

5.1 Tolerances

The tolerance of the impact speed is ± 5% for the 6.4 and 9.7 km/h impacts and +5/-0 percent for the 13 km/h impacts.

5.2 Installation conditions of test item

Test Procedure I requires that the test item shall be mounted on the rail car in direct contact with the floor and secured using the approved or specified tie-down method.

Test Procedure II requires that the test item be secured to the railcar in a manner such that the test item suspension is rendered mostly ineffective.

Test Procedure III requires that the test item be secured to the shock machine as described in paragraph 5.2 of method 403.

5.3 Test Conditions

5.3.1 Test Procedure I (taken from Ref (3))

The test item shall be mounted on a cushioned coupler car. The railcar containing the item to be tested should travel at a specified speed and collide with a stationary railcar or railcars (up to five) having a total gross mass of 113400 kg (250,000 lbs). The airbrakes of the non-moving railcar(s) shall be set in the emergency position, and the couplers shall be compressed. If the test item can be shipped in only one orientation, the railcar shall be impacted once at speeds of 6.4, 9.7, and 13 km/hr in one direction and 13 km/hr in the opposite direction (4 impacts). If the test item can be shipped in more than one orientation, the test shall be repeated for each transportation orientation.

NOTE: Speeds are mandatory for equipment to be transported by rail in the USA.

Blockings and tie-downs shall be inspected after each impact. If damaged, they shall be repaired and the test shall be performed again starting with the lowest impact speed. Failure of tie-down attachments considered built in parts of the equipment shall constitute a failure. Repair and retesting will be required.

5.3.2 Test Procedure II (taken from Ref (4))

The test item is positioned on a stationary test car and is impacted by another railcar (impact car) which is set in motion by a locomotive at an initial speed of 5 km/h. The impact speed is gradually increased (10 km/h maximum) until the required acceleration level and pulse width are achieved. If the specified acceleration cannot be achieved at an impact speed of 10 km/h, the mass of the impact car must be increased. The required levels are :

Axis	Peak Acceleration, g	Pulse Width, ms
Longitudinal	4.0	50
Lateral	0.5	50
Vertical	0.3	50

It is unlikely that the accelerations and pulse widths for the lateral and vertical axes will be met simultaneously with those in the longitudinal axis. Therefore, the tolerances specified in the Test Instruction should take account of this uncertainty.

5.3.3 Test Procedure III :

Test Procedure III is a laboratory simulation applicable to items fitted onto or transported by railway vehicles.

See paragraph 1.3 of Annex A, Method 403, for test severities.

6 FAILURE CRITERIA

The test item performance shall meet all appropriate specifications requirements following the rail impact test.

7 REFERENCES

1) IEC TC9 WG21 Draft 12th Revision 1996 (9/1371)

2) Sandia Laboratories Report SAND76- 0427, Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks.

3) MIL-STD 810F

4) RIV Anlg II Verladevorschriften Band I und II (taken from the Guidelines/Requirement of the European Railway Administration)

METHOD 417

SRS SHOCK

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GUIDANCE FOR INITIAL TEST SEVERITIES

ANNEX B

TECHNICAL GUIDANCE OF THE DERIVATION OF NON CONVENTIONAL TEST WAVEFORMS

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TECHNICAL GUIDANCE ON DERIVATION OF NON CONVENTIONAL TEST WAVEFORMS

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ANNEX E

REFERENCE / RELATED DOCUMENTS

METHOD 417

SRS SHOCK

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the effects of complex transient responses which are incurred by systems, subsystems and units, (hereafter called materiel) during the specified operational shock conditions. The test method centers on the use of the shock response spectrum (SRS) and techniques associated with the SRS.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified complex transient responses without unacceptable degradation of its functional and/or structural performance. It is particularly useful for tailoring shock responses where measured data are available for the operational environment, and when used for this purpose this test method is the preferred alternative. The test method is based primarily on the use of a electrodynamic or a electrohydraulic vibration generator with an associated control system used as a shock test machine. This method precludes the use of more traditional shock test machines such as the shock drop table. If it can be demonstrated that the materiel exposure shock is more of a classical form i.e., half-sine, final sawtooth, or trapezoidal then Method 403 is recommended.

AECTP's 100 and 200 provide additional guidance on the selection of a test procedure for a specific shock environment.

1.3 Limitations

This test method is not intended not cover close proximity gun blast, nuclear blast, underwater explosion and safety drop. Pyrotechnic shocks are covered by Method 415.

It may not be possible to simulate some in-Service operational high amplitude, high frequency responses because exciter power constraints or fixture limitations may prevent the satisfactory application of the SRS shock pulse to the test item.

2. GUIDANCE

2.1 Effects of Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel responds to complex shock environments.

a. materiel electronic circuit card malfunction, electronic circuit card damage, electronic connector failure,

b. changes in materiel dielectric strength, loss of insulation resistance, variations in magnetic and electrostatic field strength,

c. permanent mechanical/structural deformation of the materiel as a result of overstress of materiel structural and non-structural members,

d. collapse of mechanical elements of the materiel as a result of the ultimate strength of the component being exceeded,

e. materiel failure as a result of increased or decreased friction between parts, or general interference between parts,

f. fatiguing of materiel (low cycle fatigue),

g. intermittent electrical contacts,

h. cracking and rupturing of materiel.

2.2 Use of Measured Data

Measured data from a specific operational environment should be used to develop the test severity levels. It is essential to utilize measured data where a precise materiel response simulation is required. Sufficient measured data should be obtained to adequately describe the environmental conditions which the materiel will experience. If possible, the measured data should be used to construct a statistical description of the environment against which the statistics of the materiel response from testing may be compared (see also AECTP 200, leaflet 2410). In any case, use of measured data for specifying test severity levels must follow guidelines for rational processing of the data to provide environmental envelopes etc.

2.3 Sequence

The effect of shock induced stress in the materiel may affect the materiel performance under other environmental conditions such as vibration, temperature, altitude, humidity, pressure, leakage, EMI/EMC etc. or any combination of these environmental conditions. If materiel is likely to be sensitive to a combination of environments, then it is essential that the materiel be tested to the relevant environmental combinations simultaneously.

Where it is considered that a test with combined environments is not essential or impractical to configure and it is required to evaluate the effects of materiel response to shock with the materiel response to other environments, then a single test item should be exposed to all relevant environmental conditions. The order of application of the environmental test should be compatible with the Service Life Environmental Profile.

2.4 Choice of Test Procedure

There is only one procedure for SRS shock testing.

2.5 General Information for Shock Simulation

2.5.1 Recommended procedures for developing test waveforms from SRS are provided in Annexes B and C. It should be noted that there is no unique amplitude time history pulse associated with a given SRS and selection of an artificially generated time history pulse from a given SRS must (1) resemble the measured materiel response in amplitude and general shape and (2) have a duration corresponding closely with the duration of the measured materiel response.

The test specifier has the responsibility to verify that time history used to generate the SRS in the test laboratory is compatible in terms of amplitude and duration with the time history measured during operational condition. In all cases, it is essential that any test waveform developed from an SRS be agreed to by the Test Specifier. If the test laboratory does not have access to this operational time domain data, than a statement to this effect shall be included in the test report.

2.5.2 Many operational shock environments produce materiel response of a complex nature. To assess the structural integrity and the functional performance it is necessary to subject the materiel to a close representation of the materiel's expected in-Service environment. Only in some very special cases will the materiel response be adequately replicated by use of classical pulses e.g., half-sine, terminal peak saw tooth, trapezoidal, etc. on traditional shock test machines. The availability of computer based vibration generator control systems has made possible a more realistic replication of measured or predicted materiel response shock environments on vibration generator systems. Test methods can be implemented that allow tailored use of such equipment to reproduce the materiel response to operational shock environments. With the advent of modern vibration generator, capable of reproducing most field measured or predicted complex amplitude time history waveform, the utilization of classical shock tests has become a less desirable mode of testing because of the potential for over test in certain frequency ranges and under test in other frequency ranges and the effort needed to properly calibrate the traditional shock machines. The general information in this section is primarily directed towards the test replication of complex material response on modern vibration generator.

2.5.3 The ability of exciter systems to apply shock or transient waveforms to a test item is limited by the force, acceleration, velocity and displacement capabilities of the vibration generator system used. Configuring tests such that the velocity and displacement capabilities of the vibration generator system are not exceeded is important. It is often found necessary to adjust the amplitude or phase of low frequency components of the complex waveform to ensure that the velocity and displacement requirements for the test remain within acceptable limits. There exist several rationales for developing the compensation pulse. It is also important to note that there are substantial differences in response variable ranges in different frequency regions between electrodynamic vibration generator systems and electrohydraulic vibration generator systems. In general electrodynamic vibration generator systems are capable of test to 2000 Hz and beyond with reduced low frequency displacement capability. Electrohydraulic vibration generator systems are capable of test to perhaps 1000 Hz but with substantial low frequency displacement capability.

2.5.4 Since shock tests are run in an open-loop mode on vibration generator control systems it is essential that the input signal in the form of voltage be adjusted before the test. It is also important to recognize that the goal of the test is the precise replication of the predicted or measured materiel response. To permit the vibration control system to achieve the required test waveform it is almost always necessary to apply several precursor pulses to the test item at greatly reduced amplitude. The relationship between the vibration control system voltage and the measured response under these precursor pulses is then used to adjust the input voltage signal to achieve the desired materiel response waveform. In order to avoid unnecessary stress to the test item it is recommended that a dynamic representation of the test item be used to compensate the vibration control system output waveform, however the dynamic response characteristics of the representation must be very similar to those of the actual test item to which the full amplitude waveform is to be applied. If a dynamic representation is not available, then the Test Specifier must state the number of precursor pulses to be applied without producing unacceptable fatigue and the maximum test amplitude level not to be exceeded. If response averaging of the system transfer function is used in the compensation process, then usually three precursor pulses will be adequate to ensure a minimum deviation from the full level response requirements. For rare cases where the test item responses in a nonlinear manner as a function of response level, waveform compensation may not be possible and recourse must be made to testing at full level using a dynamic representation of the test item..

2.6 Derivation of Test Waveform

Guidance on deriving a test waveform from measured time domain data is provided in Annexes B and C.

2.7 Control and Tolerancing Strategies

2.7.1 For the test control system to replicate the required materiel response test waveform at the test item reference point, the drive waveform applied to the vibration generator is adjusted automatically by use of Fourier processing methods. For verification of the proper application of the test waveform to the materiel the following comparisons should be made:

a. the time history measured at the materiel response reference point is compared directly with the provided time history (see Paragraph 2.7.4.). In general this is a visual inspection of the waveform amplitude peak levels and the general waveform shape,

b. the SRS measured at the materiel response reference point is compared with the SRS specified by the Test Specifier.

The general method used for the control of the test conditions using both time domain inspection and shock response spectra comparison is shown diagrammatically in Figure 1.

2.7.2 For relatively simple measured waveforms (few zero crossings) the direct comparison of waveform shapes in the time domain is the most suitable approach. The tolerancing of such simple waveforms as found in classical shock is essentially the same as that for half-sine, final peak sawtooth and trapezoidal pulses as defined in Method 403. The tolerance boundary is placed above and below the required waveform. The test item response waveform as measured at the reference point should be within these boundaries. In cases in which relatively simple waveforms are utilized in conjunction with a vibration generator control system the methodology of such a test control and verification is illustrated in Figure 2.

2.7.3 For complex waveforms (many zero crossings) the use of the SRS as the basis for materiel response comparison and verification is more applicable. An example of a typical complex waveform is shown in Figure 6 of AECTP 200, Leaflet 249/1.

Tolerancing is achieved by placing boundaries above and below the required SRS. The upper boundary is often the required and not to be exceeded materiel shock response level which is generally a conservative estimate of the in-Service environment SRS. The SRS derived from the waveform sampled at the materiel response reference point should be within these boundaries. The methodology of such a test controlled in this manner is illustrated in Figure 3.

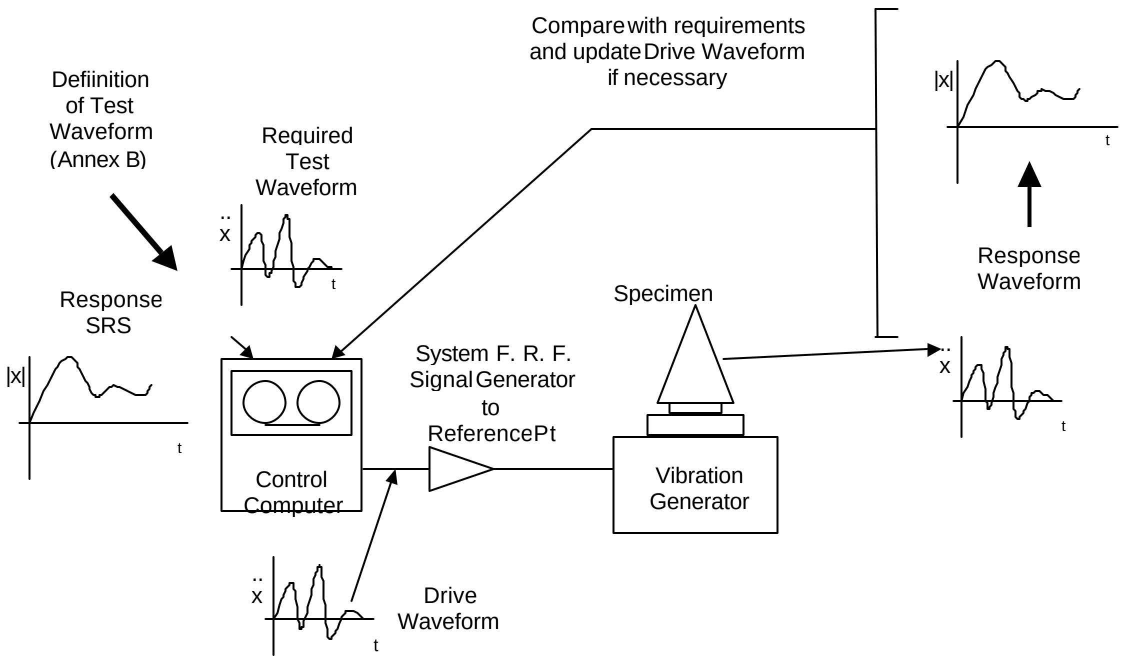

Figure 1. General methodology of the SRS shock test.

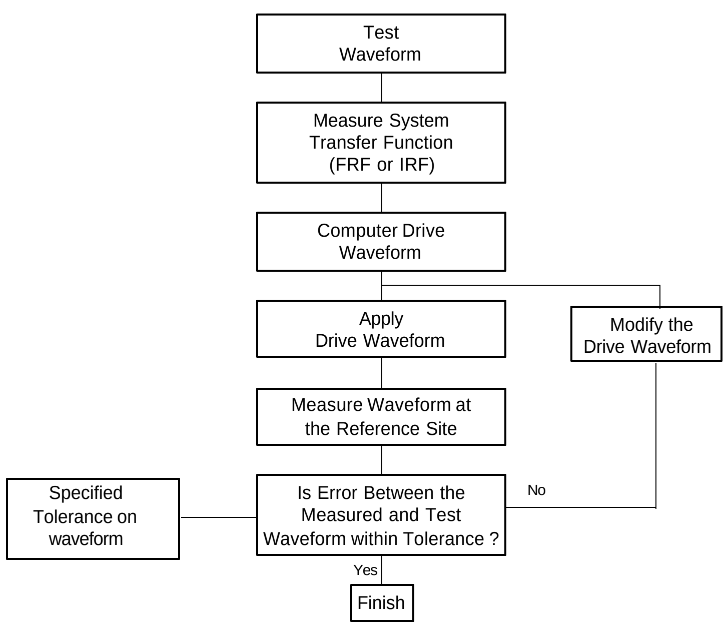

Figure 2. Methodology for the SRS shock test when controlled on time domain parameters.

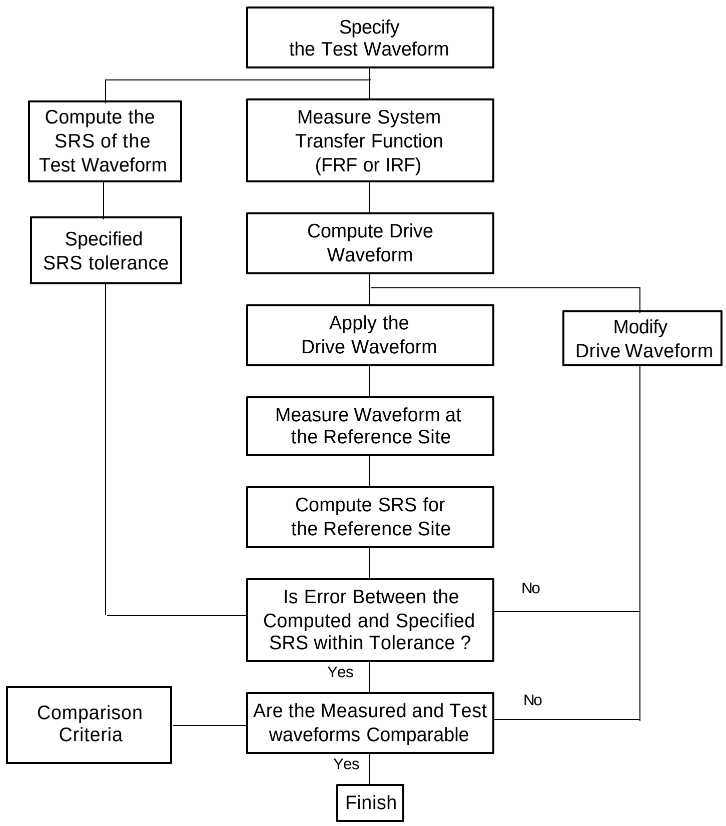

Figure 3. Methodology for SRS shock test when controlled on shock response spectra.

2.7.4 As mentioned in Paragraphs 2.5.1 and 2.7., when SRS are used for control and tolerancing purposes, additional constraint criteria may need to be applied to the time domain parameters. The need for additional constraints is a result of the fact that a single SRS may be replicated by many forms of time history pulses. Failure to accurately reproduce the original time history can result in variation in failure modes produced. When selecting these additional constraints due consideration should be taken of the original materiel response waveform. The most common two constraints used are peak amplitude distribution and/or effective pulse duration. In general a peak amplitude constraint is applicable when failure of the test item could occur as a result of overstress. An effective pulse duration is applicable when low cycle fatigue is of concern. In any case the duration of the test waveform pulse should not exceed nor be shorter than the measured materiel response waveform by more than 15% of total duration. When in doubt, peak amplitude should be used as the primary constraint with the peak amplitudes of the replicated waveform within 25% of the peak amplitudes of the measured or predicted test waveforms.

The two constraint criteria referred to above do not preclude the use of alternative methods to ensure that the characteristics of the test pulse are representative of the predicted or measured materiel response characteristics. More complex alternative constraints may utilize either Fourier spectra, energy spectral density, time domain/frequency domain energy measure. When such alternative constraint criteria are to be used the approach should be clearly stated in the Test instruction along with supporting documentation and rationale for use of the alternative criteria.

2.8 Control, Monitor, Fixing Reference Points

For the purpose of this test the definitions of the fixing, monitor, control and reference points are as follows:

a. A fixing point is defined as a part of the test item in contact with the mounting fixture or vibration table at a point where it is usually fastened in-Service.

b. A control point is a position at which measurements are made to allow the transient excitation to be controlled to within specific bounds. In general, the control point on the test item is chosen such that local resonances of the materiel are a minimum but the overall response of the test item is well described. If local resonances are not kept to a minimum there may be difficulty in compensation of the test waveform.

c. A monitor point is a position at which measurements are made in order to establish knowledge of the response behavior of the test item.

d. The reference point is the point at which the materiel response measurements are taken (or derived) to confirm that the requirements of the Test Instruction are satisfied. The reference point should be stated in the Test Instruction. It may be a monitor point, a control point or a “conceptual point” created by manual or automatic processing of the signals from several control points.

2.9 Materiel Operation

The test item should be operated and its performances measured and noted as specified in the Test Instruction or relevant specification.

3. SEVERITIES

3.1 General

When practicable test severities will be established using predicted or measured data acquired with consideration of the projected in-Service life profiles and other relevant available data. In general, for complex pulses there are no initial test severities covering specific operational environments for this test method (Further information on response characteristics for specific operational environments is given in AECTP 200).

3.2 Supporting Assessment

It should be noted that the test selected may not be an adequate simulation of the complete environment and consequently, a supporting assessment may be necessary to complement the test results and justify the selected test rationale.

3.3 Isolation System

Materiel identified for use with shock isolation systems should normally be tested with its isolators in position. If it is not practical to carry out the shock test with the appropriate isolators, or if the dynamic characteristics of the materiel are variable, then the test item should be tested without isolators at a modified severity specified in the Test Instruction.

3.4 Subsystem Testing

When identified in the test plan, sub systems of the materiel may be tested separately and can be subjected to different shock severities. In this case the Test Instruction should stipulate the shock severities specific to each subsystem.

4. INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item.
b. The definition of the test item.
c. The test severities including for each axes and direction :
d. the specific SRS,
e. the associated time history,
f. the number of pulses to be applied,
g. The type of test : development, qualification, etc.
h. The method of mounting, including isolators if applicable.
i. The operation or non-operation of the test item during test.
j. The packaging conditions, if applicable.
k. The limits for cross axis motions, if applicable.
l. The requirements for operating checks, if applicable.
m. The reference, control, and monitor points to be used.
n. The tolerances to be applied.
o. The details required to perform the test.
p. The definition of the failure criteria, if applicable.

4.2 If required

a. The climatic conditions, if other than standard laboratory conditions.
b. The effects of gravity and the subsequent precautions.
c. The value of the tolerable magnetic field.
d. The tolerances, if different or additional to those in para. 5.1.

5. TEST CONDITIONS

5.1 Tolerances

5.1.1 Complex Waveforms

Unless stated otherwise in the Test Instruction the shock response measured at the reference point shall not deviate from the specified requirements by more than the values quoted below:

For tests controlled on the SRS parameters the tolerance on the SRS amplitude should be $\pm$1.5 dB over the specified frequency range. Over a limited frequency range, a tolerance of $\pm$ 3 dB is permissible. Additional constraints on time domain parameters (e.g., peak amplitude and/or effective duration) are usually necessary to ensure that an adequate simulation is achieved. These additional constraints are described in Paragraphs 2.5.1 and 2.7.4. and those adopted shall be quoted in the Test Instruction.

5.1.2 Simple Waveforms

The tolerances on relatively simple waveform shapes from measured data should be derived from those given in Method 403 Classical Waveform Shock, and when applicable, should be compatible with tolerances given in Paragraph 5.1.1 for the SRS associated with the pulse.

5.2 Installation Conditions of the Test item

Unless otherwise stated in the Test Instruction for the materiel, the following will apply :

a. The test item shall be mechanically fastened, using its normal means of attachment, to the shock generator by means of a fixture. Any additional stays or straps should be avoided.

b. The mounting configuration shall enable the test item to be subjected to the specified SRS. The fixing points of the test item should move, as far as practicable, in phase and in straight lines parallel with the line of motion. It may be necessary to use different test fixtures for each test axis.

c. Any connections to the test item, such as cables, pipes, wires, shall be arranged so that they impose similar dynamic restraint and mass to its in-Service configuration. Any external connections for measuring purposes shall add minimum restraint and mass.

d. Where gravitational force is important, or when in doubt, the test item shall be mounted so that the gravitational force acts in the same direction as it would in-Service use.

e. Subject to the guidance given in Paragraph 3.3, materiel intended for use with isolators shall normally be tested with the isolators on the test item in position.

5.3 Test Preparation and Preconditioning

If required, any structural dynamic characterization tests shall be undertaken and recorded as stipulated in the Test Instruction.

A number of applications of the test pulse is usually necessary before the control equipment is able to achieve an acceptable response at the reference point. This is precursor activity usually performed on a dynamically representation of the test item. (see Paragraph 2.5.4).

If required, the test item shall be stabilized to its initial climatic and other conditions as stipulated in the Test Instruction.

5.4 Operational Checks

All operational checks, including visual examinations, shall be undertaken in accordance with the Test Instruction. The final operational checks should be made when the materiel is at rest and pre-conditioning conditions, including thermal stability, have been obtained.

5.5 Procedure

Step 1. Undertake the preliminary tasks and precondition as stated in Paragraphs. 5.2. and 5.3.

Step 2. Implement control strategy, including reference, control and monitoring points, as per the guidance given in Paragraphs 2.5, 26 and 2.7.

Step 3. Undertake the initial operating checks as stated in Paragraph 5.4.

Step 4. Apply the transient pulse at full level to the test item in the axes and directions stated in the Test Instruction.

Step 5. Undertake the final operating checks.

Note : Where the test program requires a number of different pulses for the application of different types of shock, or vibration, it may be possible to complete the entire sequence of tests for one axis, provided prior agreement is obtained from the Test Specifier.

6. FAILURE CRITERIA

The test item performances shall meet all appropriate specification requirements during and following the completion of the shock conditions.

ANNEX A

GUIDANCE FOR INITIAL TEST SEVERITY

There are no initial test severities for SRS controlled shock tests. For guidance on developing tailored test severities, refer to Annexes B, C and D.

ANNEX B

TECHNICAL GUIDANCE ON THE DERIVATION OF NON-CONVENTIONAL TEST WAVEFORMS

1. DEFINITION OF THE TEST WAVEFORM

1.1 General

Current facilities and techniques allow the derivation of test waveforms from measured and environmental data by several different methods. The most common approaches include the derivation of test waveforms from:

a. Direct capture of measured in-Service data

b. A shock response spectrum

c. Fitting of an analytically described waveform

1.2 Test Waveforms Derived from Analog Capture

The transient capture facility available on most computer based control systems may be used to acquire a transient waveform directly. However, the use of waveforms acquired by this approach may be limited by the following:

a. The requirements of the test waveform may be beyond the physical limitations of the generator in terms of either thrust, velocity or displacement

b. The statistical uncertainty associated with a single measured event

The first limitation can sometimes be resolved by modifying the test waveform to ensure that the generator velocity and displacement constraints are met. This is usually achieved by modulating the measured in-Service data with a low frequency waveform to ensure the final velocity and displacement are zero. The second limitation can be overcome if sufficient confidence can be achieved in the test data.

1.3 Test Waveforms Derived from a Shock Response Spectrum

Where measured data exist which relate to a particular shock environment, but which, due to complexity, are not suitable as test criteria, the derivation of a test waveform from a shock response spectrum may be appropriate. Unfortunately many test waveforms can be derived from a single specific shock response spectrum. As such due cognizance should be taken of the nature of the original time history. In these circumstances the derived waveform should always be agreed with the Test Specifier.

A suitable method of deriving a test waveform from a shock response spectrum is discussed below under Generation of Test Waveforms from Shock Response Spectra. The procedure is used to create a test waveform described as an analytical function. The derivation of shock response spectra from field data is also addressed in Determination of Shock Response Spectra from Field Data.

1.4 Test Waveforms Described by Analytical Functions

Where measured data exhibit a repeatable form in the time domain or are of a simplistic nature, it may be possible to fit a mathematical or analytical function to define the shock waveform. It may be necessary when using this approach to modulate the required waveform to ensure that the test waveform is within the physical capabilities of the vibration generator.

2. GENERATION OF TEST WAVEFORMS FROM SHOCK RESPONSE SPECTRA

2.1 The use of summations of oscillatory type pulses has been recognized as a possible method for representing certain types of shock environment. With the development of digital control techniques it is possible, by using these techniques to reproduce very complicated time histories.

2.2 Two types of oscillatory pulse have attained fairly widespread use. These are the decaying sinusoid, which has the form

$$A = A_0 e^{-\zeta \omega t} \sin \omega \qquad \text{Equation 1}$$

and the wavelet type pulse which has the form

$$A = A_0 \sin \omega t \sin ? \; t \qquad \text{Equation 2}$$

Acceptable results may be obtained by using either of these methods. The approach, specifically considered here, is that using decaying sinusoids. However, the comments are largely applicable to both methods.

2.3 The basic procedure for deriving a suitable waveform from a specified shock response spectrum, illustrated in Figure 1, is as follows:

a. Firstly an initial estimate is made of the characteristics of the required waveform.

b. This estimate is then improved using an iterative procedure.

2.4 Obtaining initial estimates of the test waveform may be considered to have three aspects, namely the identification of the frequencies of the important sinusoidal components, the determination of the decay rate for each component and the determination of the amplitude of each decaying sinusoid.

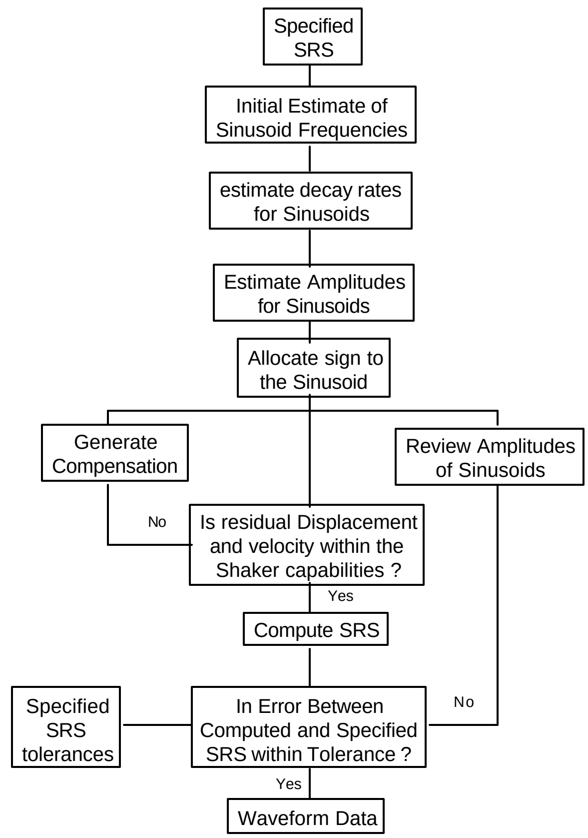

Figure B1. Generation of a test waveform from shock response spectrum.

2.5 For those shock response spectra which exhibit clearly identifiable peaks, the initial choice of frequency components is relatively straight forward. However, where no obvious peaks exist reference to the Fourier spectrum or Energy Spectral Density of the field data may provide an insight into a suitable choice of starting frequencies.

2.6 The decay rate of each sinusoidal component may be determined from either inspection of the time response or its associated shock response spectra. Decay rates can be obtained from the time response using techniques such as logarithmic decrement. The shape of the SRS, as shown in Figure B2 can also aid the choice of decay rates.

2.7 The amplitudes of the sinusoids can be determined from Figure B3. Figure B3 represents the normalized maximum response of a single degree of freedom system to a decaying sinusoidal input as a function of the decay rate of the sinusoid. The plot is for various levels of damping in the single degree of freedom system. Figure B4 is a plot of the inverse of Figure B3, that is the input level per unit maximum response of a single degree of freedom system with 5% damping. The amplitude of the sinusoidal component may therefore be determined by multiplying the value of the test shock response spectrum at the frequency of the decaying sinusoid by the input level corresponding to the appropriate decay rate from Figure B4.

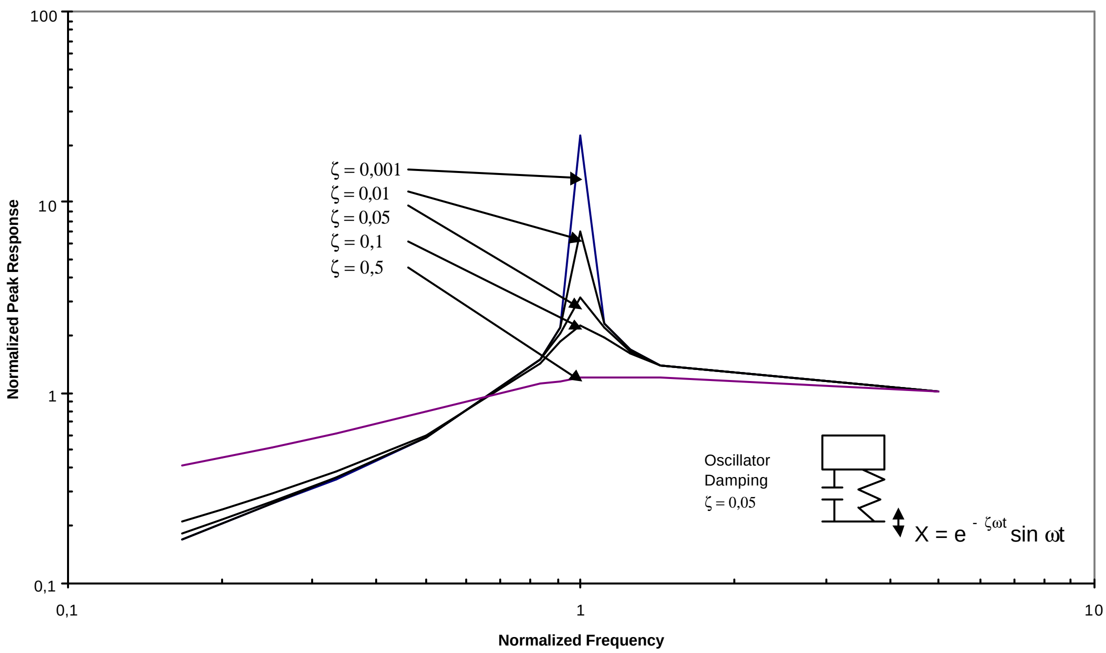

Figure B2. Normalized maximum response.

2.8 The sign of the amplitude of the sinusoidal components may be either positive or negative. The choice of sign does not have an effect on the shock response spectrum of the composite waveform. If the spectrum contains discrete peaks then a superposition of in-phase waveforms will accentuate the peaks and valleys in the spectrum. If, however, the spectrum is without marked peaks the synthesis of component waveforms combined alternatively in and our of phase will tend to smooth the spectrum.

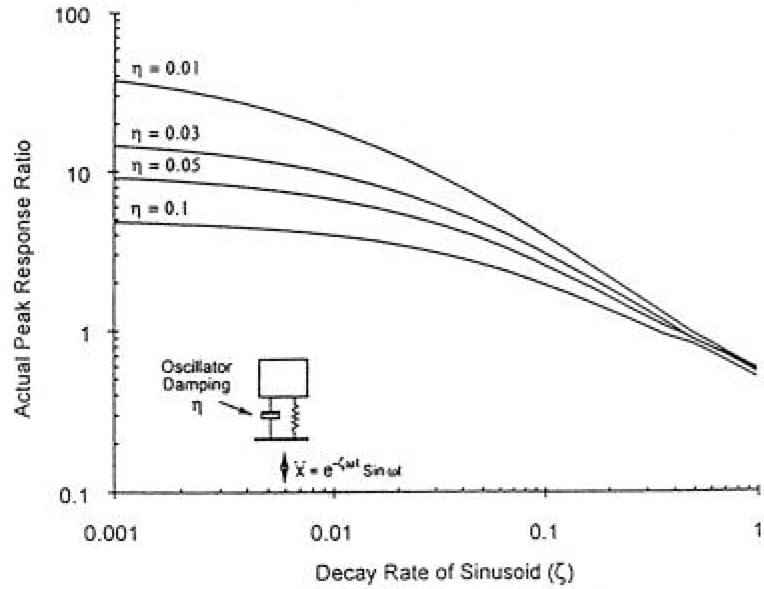

Figure B3. Response per unit imput

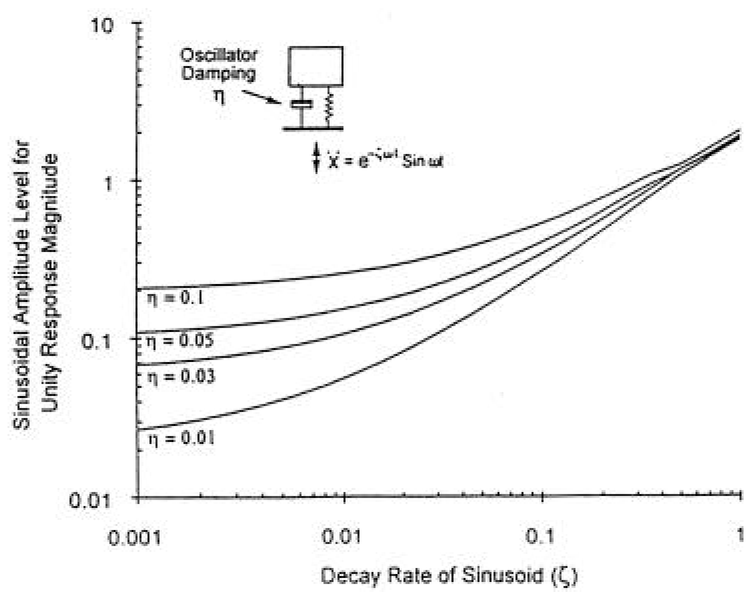

Figure B4. Input per unit response.

2.9 An important point to note is that the final velocity and displacement of the derived waveform may not zero. In order to overcome potential problems with the vibrator a compensation pulse is normally added to the synthesized time history. In some proprietary shock synthesis programs this compensation pulse is added without user intervention. However, in others compensation pulse frequency and decay rate must be selected. Generally, a compensation pulse should be applied with a frequency of approximately one-half to one-third the minimum frequency in the shock response spectrum with a decay rate approaching 100% of critical damping. Using suitable values of compensation pulse frequency (ω_m) and decay rate (ζ_m) the compensation pulse amplitude (A_m) and delay time (t) can be computed (using Equations 3 and 4) to control residual velocity and displacement respectively. In this case the delay time is that between initiation of the compensation pulse and the subsequent start of the decaying sinusoids.

$$\frac{A_m}{\omega_m\left(\zeta_m^2+1\right)} = -\sum_{i=1}^{n} \frac{A_i}{\omega_i\left(\zeta_i^2+1\right)} \qquad \text{Equation 3}$$

$$\frac{A_m \pi}{\omega_m\left(\zeta_m^2+1\right)} = \frac{2\zeta_m A_m}{\omega_m^2\left(\zeta_m^2+1\right)^2} + \sum_{i=1}^{n} \frac{2\zeta_m A_m}{\omega_i^2\left(\zeta_i^2+1\right)^2} \qquad \text{Equation 4}$$

A_i, ω_i, ζ_i are the amplitude, cyclic frequency and decay rate of the ith sinusoidal component.

2.10 It is important to note that the above procedure will develop a shock response spectrum based on the assumption that the individual sinusoidal components act independently. An iteration process is then required whereby component amplitudes and decay rates are varied to obtain a better fit to the shock response spectrum. This procedure is, in general, built into proprietary shock synthesis computer programs.

3. THE DETERMINATION OF SHOCK RESPONSE SPECTRA FROM FIELD DATA

3.1 This section gives guidelines for the generation of shock response spectra from field data. In general each axis of the field data for a specific location will have a different shock response spectrum.

3.2 The shock response spectra required for the determination of the test shock response spectrum will be obtained from reduction of the measured time histories of the transient event.

3.3 The duration of the shock input time history used for the response spectrum calculation should be twice the effective pulse duration starting at a time to include the most significant data prior to and/or following the effective duration.

3.4 The shock response spectra analysis parameters, damping, frequency interval and frequency range, should be selected from consideration of the shock waveform and the equipment to be tested. However, useful starting values are for a damping ratio of 5% of critical damping (Q = 10) at a sequence of resonator frequencies at intervals of 1/6th octave or smaller to span at least 5 Hz to 2,000 Hz.

3.5 The spectrum used to define the test shock response spectrum should be a composite of positive and negative directions commonly called the maximax spectrum. It should be the maximum value obtained from both the primary and residual responses.

3.6 When a sufficient number of spectra is available an appropriate statistical basis should be employed to determine the required test shock response spectrum. Guidance for such statistical analysis is found in Annex D.

3.7 As a general guide for the classical waveform shock type of test, use of 95.5% population limits is usually applicable for most applications. However, for certain types of test (notably function and reliability assessment) the use of smaller population limits (typically 68.3%) may be more appropriate. For some safety demonstration testing population limits of 99.7% or greater may be required. For some material the design requirements may specify alternative values to be adopted. Selection of these population limits must be consistent with the statistical procedures employed in Annex D.

3.8 When insufficient data are available for statistical analysis (the use of the above guidance becomes suspect for less than five samples) an increase over the maximum available spectral data should be used to establish the required test spectrum in order to account for variability of the environment.

ANNEX C

TECHNICAL GUIDANCE ON THE PERFORMANCES OF SHOCK TESTS

1. SCOPE

This annex is intended to provide guidance and definitions that will be useful in setting up and performing shock tests. It is not intended to be a textbook on shock.

2. LIMITATIONS

Shock testing can be performed on test apparatus designed specifically for this purpose. Alternatively, it may be possible to use a vibr ation generator, within certain mechanical and electrical

Limitations. This annex applies only to shakers.

2.1 Displacement

The specification defines, either through the wave form or through the shock response spectrum, the maximum acceleration to be reached in a given time. This results in a transient displacement whose instantaneous value should remain within the limits of the generator. Generally speaking conventional wave forms require larger displacements than the shock response spectra simulated by oscillatory transients.

2.1.1 Electrodynamic Shakers

These shakers are normal vibration test shakers, usually with a 100g armature acceleration limit and either a maximum stroke of 25 mm (1 inch) or, with some lateR machines, 50 mm (2 inches). Some shock testing is possible within the limitations above and the pre and post pulse deviations permitted by the test instruction. The position of the neutral of the coil can be set to take into account possible dissymetries in the transient displacement. Overtravel of the armature at shock test energy levels can severely damage the shaker.

2.1.2 Electrohydraulic Shakers

The use of suitable electrohydraulic shakers for classical pulse shock testing circumvents the major limitation of electrodynamic shakers of limited displacement. Th e major limitation of electrohydraulic shakers is of frequency response although advanced systems are capable of 1 kHz. Their load, therefore acceleration, capability often exceeds that of the electrodynamic types available.

2.2 Velocity

2.2.1 Electrodynamic Shaker Velocity Limitations

The maximum velocity of these shakers is limited by the acceleration and displacement limits imposed by system electrical and mechanical design parameters.

2.2.2 Electrohydraulic Shaker Velocity Limitations

Velocity limitations are a result of hydraulic flow restrictions and vary from system to system. Systems designed for this type of testing may have parallel servo valves and hydraulic accumulators which gives wider limits on velocity and frequency bandwidth.

2.3 Acceleration

2.3.1 Electrodynamic Shaker Acceleration Limitations

Acceleration is limited by the amount of electrical power that can be fed through the armature, the mechanical strength of the armature and table assembly, its total load including self mass and internal losses and the mechanical and electrical impedances of the test system and load. It should be noted that the mechanical impedance term, above, includes anti-resonance effects in the frequency domain which can absorb a disproportionate amount of the available power.

2.3.2 Electrohydraulic Shaker Acceleration Limitations

Since, within other limitations of these shakers, tests can be controlled by a displacement/time or force/time method the effects of test item anti-resonances play a much less important role within the test. Since these shakers are self stopping when the servo valves dose there is much less chance of system over-run damage and therefore higher accelerations can be safely achieved.

2.4 Frequency Range

Electrodynamic test systems operate in a higher frequency band than their electrohydraulic counterparts.

2.4.1 Electrodynamic Shaker Frequency Range

The useful frequency range of these shakers is severely limited at low frequencies by their amplitude limitation and at high frequencies by modal density. Modal density of the test item, its support assembly and of the shaker head and armature dictates that energy absorbent anti-resonances will be present in sufficient magnitude to account for any reasonable available power when driving from a frequency response function oriented pulse shaping controller, as most current shaker shock controllers are.

2.4.2 Electrohydraulic Shaker Frequency Range

There is little limitation at the low frequency end of the spectrum other than dictated by the pressure and flow characteristics of the system, the available stroke and mechanical strength. At high frequencies there is a finite limit related to the mass/stiffness of both the hydraulic medium and the servo valve operating speed. The effects of this are minimized in high performance systems by using parallel accumulators and servos with short hydraulic column lengths between accumulator and ram.

2.4.3 Electrodynamic Shaker Power Amplifier

The combination of instantaneous voltage and output current values (e and i) necessary is limited and depends on the construction of the amplifier, tube or solid circuit type.

2.4.4 Electrohydraulic Shaker Power System

Since, when used for shock testing, This type of shaker does not normally draw its power directly from a hydraulic line it only requires sufficient power to recharge its accumulators to the required pressure in a sufficiently short time commensurate with being ready to perform the next required shock. Where the shaker runs from a hydraulic main pressure system serving a whole test facility it is necessary to use local accumulators when shock testing to minimize line pressure fluctuations.

3. WAVE FORM SHOCK GENERATION

3.1 Generalities

During an actual shock test, the materiel is always at rest before and after the total shock time history, therefore the change in total velocity is zero. This fact dictates the need to precede and/or follow the specified pulse with additional pulses. These pre-and post pulses must be chosen such that, without changing the result of the test, they accumulate and/or dissipate energy in such a way as to zero both initial and final velocity.

Example in case of a true half sine:

$$0 \le t \le D$$

$$a(t) = A \sin\left(\frac{\pi t}{D}\right)$$

$$v(t) = -\frac{D\,A}{\pi} \cos\left(\frac{\pi t}{D}\right)$$

when t = 0,

$$v(t) = -\frac{D\,A}{\pi} \neq 0$$

when t = D,

$$v(t) = \frac{D\,A}{\pi} \neq 0$$

3.2 Case of Half Sine

In practice, we may use one on three different types of "half sine":

- Impulse (half sine with post-pulse)
- Impact with perfect rebound (half sine with post- and pre-pulse) or shock with over turning
- Impact without rebound (half sine with pre-pulse)

In the following, we will study only the first two, which arethe most used.

The computation below is made for a semi-sinusoidal shock. The same method can be applied for other wave forms.

3.2.1 Impulse

From 0 to D, we obtain:

$$a(t) = A \sin \omega t \left(\omega = \frac{\pi}{D} \right)$$

$$v(t) = -\frac{A}{\omega} (\cos \omega t - 1) \text{ initial conditions } : v(0) = 0$$

$$d(t) = \frac{A}{\omega} \left(t - \frac{\sin \omega t}{\omega}, \text{ for } t = 0, d(t) = 0 \right)$$

From D to t_1, we obtain:

$$a(t) = -pA$$

the total duration is

$$t_1 = D\left(1 + \frac{2}{\pi p}\right)$$

$$v(t) = -pA(t - D) + 2\frac{A}{\omega}, \text{initial conditions } v(t_1) = 0$$

we have the continuity for the displacement to t = D, then:

$$d(t) = -pA\frac{t^2}{2} + At\left(Dp + \frac{2}{\omega}\right) - AD\left(\frac{1}{\omega} + D\frac{p}{2}\right)$$

we find the maximum displacement for t = t_1

$$d_{max} = p\frac{A}{2}\left(\left(\frac{2}{p\omega}\right)^2 - D^2\right)$$

If the relative masses of the moving part (M_m) and of the body (M_c) of the exciter are taken into account the value of the acceleration becomes:

$$G = \frac{A}{g_n + \left(1 + \frac{M_m}{M_c}\right)}$$

(Only if M_m is an inert mass without dampers)

3.2.2 Impact With Rebound

From 0 to t_1

a(t) = -pA

v(t) = -pAt (when t = 0, v(t) = 0)

$d(t) = -pAt^2/2$ (when $t = 0$, $d(t) = 0$)

Between t_1 and t_2

$a(t) = A \sin \omega(t-t_1)$, with $t_2 - t_1 = D$, and $\omega = \pi/D$

the equality of the acceleration curve area produces:

$t_1 p = 1/\omega$

$v(t) = -A/\omega \cos \omega(t - t_1) + cte$

the velocity should be zero with: $\omega t = \pi/2$

then: $v(t) = -\frac{A}{\omega} \cos \omega(t - t_1)$

$$d(t) = -\frac{A}{\omega^2} \sin \omega(t - t_2) + cte$$

we should have for $t = t_1$:

$$d(t) = -\frac{A}{\omega^2} \left(\sin \omega(t - t_2) + \frac{1}{2p} \right)$$

the displacement becomes maximum when $\omega t = \pi/2$

$$d_{max} = \frac{A}{\omega^2} \left(1 + \frac{1}{2p} \right)$$

From t_2 to t_3

$$t_3 = t_1 + t_2 = D\left(1 + \frac{2}{\pi p} \right)$$, the total duration is t_3, $D = t_2 - t_1$

$a(t) = -pA$

$v(t) = -pA(t - t_2) + cte$, $v(t_3) = 0$

then $$v(t) = A\left(p(D - t) + \frac{2}{\omega} \right)$$

$$d(t) = A\ t\left(p\left(D - \frac{t}{2} \right) + \frac{2}{\omega} \right) + cte$$

when $t = t_3$, $d(t) = 0$

then:

$$d(t) = A\ t\left(p\left(D - \frac{t}{2} \right) + \frac{2}{\omega} \right) - \frac{A\ p}{2} \left(D + \frac{2}{p\omega} \right)^2$$

If the relative masses of the moving part (M_m) and of the body (M_c) of the exciter are taken into account, the value of the acceleration becomes:

$$G = \frac{A}{g_n + \left(1 + \frac{M_m}{M_c}\right)}$$

(Only, if M_m is an inert mass without dampers)

3.2.3 Conclusion

The maximum displacement compared with the rest position before the shock is at least four time weaker for impact with rebound than for impulse. This fraction is two for velocity.

Thus, "1/2 sine" shock tests are usually applied using the method of impact with rebound. This is of particular advantage when a shock test is performed on a vibration generator. Adjustment of the test apparatus to deliver the specified pulse should be with dynamic representation of the test item. This is because response of the test item will affect the pulse delivered by the test apparatus. The ratio of the mass of The test item to that of The test table should be sufficiently small to ensure that waveform distortion does not exceed tolerance limits, if the test apparatus does not incorporate means to compensate for distortion. When testing with the shock response spectrum method and especially when testing with methods which add pre-and/or post-pulses to The specified pulse, if the test item incorporates shock isolators, validity of the relative motion within The isolators should be confirmed during adjustment of the test apparatus.

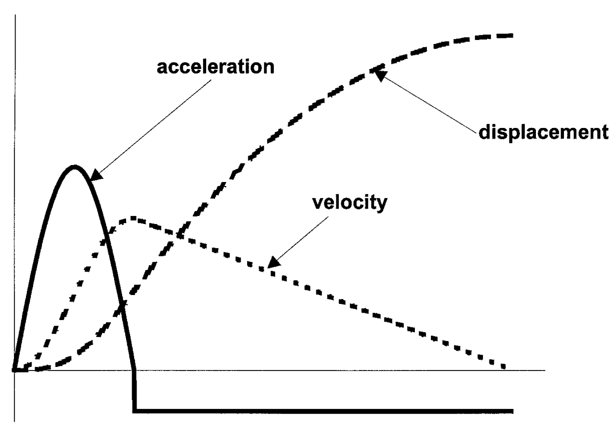

Figure C3.1. Form of Signals (Impulse).

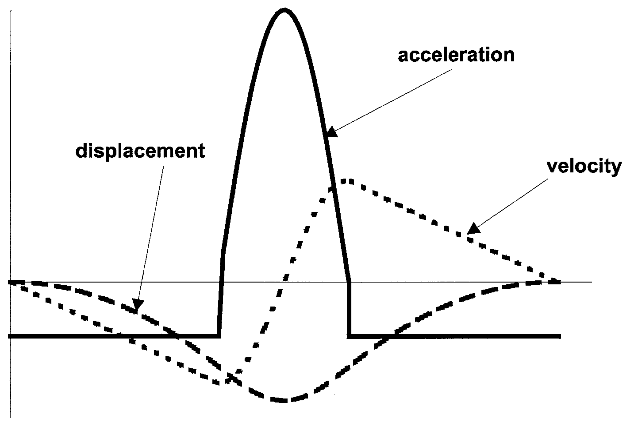

Figure C3.2. Form of Signals (Impact With Rebound).

4. SHOCK GENERATION WITH SHOCK RESPONSE SPECTRUM

As different wave forms correspond to the same shock response spectrum, a specification in the form of a shock response spectrum is less restrictive for the vibration generator and it is possible, for a given maximum acceleration, to reduce the maximum velocity in view of the frequencies range f_2f_3 in figure, method 403, where the tolerance of ±20 percent must be respected.

5. CHARACTERISTICS OF THE SHOCK RESPONSE SPECTRA

5.1 Definitions

The shock response spectrum is the envelope of the maximum response of undamped second degree linear systems, when their natural frequency f_n varies.

The response parameter can be: (see Figure C4).

- either the maximum relative displacement of the mass in relation to the base (maximum of z)
- or the absolute maximum velocity of the mass (maximum of $\dot{y}$)
- or the absolute maximum acceleration of the mass (maximum of $\ddot{y}$)

$$\omega_n = 2\pi f_n = \sqrt{\frac{k}{m}} \qquad \zeta = \frac{c}{2\sqrt{km}}$$

$$Q = \frac{1}{2\zeta_n} = \frac{\sqrt{km}}{c}$$

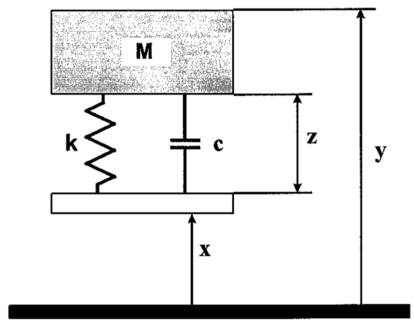

Figure C4. Linear System of a Single Degree of Freedom.

The relative displacement is more correctly linked to the constraints (damage potential), the velocity to the energy, the absolute acceleration to the forces (destructive potential) due to the shock. The balance of forces applied to the system with one degree of freedom in Figure 1 shows the differential equation of the movement:

$$m\ddot{y} + c(\dot{y} - \dot{x}) + k(y - x) = 0$$

By differentiating this equation once, twice and red ucing it to the relative displacement, we obtain the following three equations:

$$\frac{d^2\dot{y}}{dt^2} + 2x_n w_n \frac{d\dot{y}}{dt} + w_n^2 \dot{y} = 2x_n w_n \frac{d\dot{x}}{dt} + w_n^2 \dot{x} = 2x_n w_n \ddot{x} + w_n^2 \dot{x}$$

$$\frac{d^2\ddot{y}}{dt^2} + 2x_n w_n \frac{d\ddot{y}}{dt} + w_n^2 \ddot{y} = 2x_n w_n \frac{d\ddot{x}}{dt} + w_n^2 \ddot{x}$$

$$\ddot{z} + 2x_n w_n \dot{z} + w_n^2 z = -\ddot{x}$$

The comparison between equations (3) and (4) shows that, if the systems with one degree of freedom are not damped ($\xi_n = 0$) the shock response spectrum of the absolute accelerations is obtained by multiplying by $-\omega_n^2$ the shock response spectrum of the relative displacements.

The spectra are then identical, when they are rendered without dimensions by dividing:

- the absolute maximum acceleration of th e mess $\ddot{y}_m$ by the maximum acceleration $\ddot{x}_m$ of the base, $\ddot{y}_m / \ddot{x}_m$

- the relative maximum displacement of the mass z_m by the relative maximum static displacement.

As long as the damping remains slight, $Q_n > 10$, the standardized spectra of absolute accelerations and relative displacements can be considered as identical.

$$z_s = -\frac{m}{k}\ddot{x}_m = \frac{\ddot{x}_m}{w_n^2}; \frac{z_m}{z_s} = -w_n^2 \frac{z_m}{\ddot{x}_m}$$

Conversely the comparisons between equations (2) and (4) shows that, even in the case of an undamped system, the velocity response to the shock spectrum cannot be simply deduced from the relative displacement response to the shock spectrum given that if $\left|w_n^2 \dot{x}\right| = \left|w_n \ddot{x}\right|$ there is a phase shift of $\pi/2$ between velocity and acceleration.

The velocity obtained by writing $w_n^2 \dot{x} = -w_n \ddot{x}$ in the equation (2) is referred to as "pseudo-velocity" (Z).

The pseudo velocity is equal to the relative velocity $\dot{z}$ in an undamped system.

These considerations involve defining:

- the shock response spectrum of the relative displacements, S_d
- the shock response spectrum of the relative velocities or "pseudo velocities", $S_v = \omega_n S_d$
- the shock response spectrum of the absolute accelerations $S_\gamma = -\omega_n^2 S_d$

These three spectra are identical, when they are standardized respectively by the relative displacement, the maximum pseudo-velocity and maximum acceleration, $z_s, \ddot{x}_m / w_n, \ddot{x}_m$ and when the damping of the systems with one degree of freedom remains slight ($Q_n > 10$).

The shock is only generally known from the time signal of the acceleration of the fasteners of the materiel to its carrier, $\ddot{x}(t)$, the control being made practical by accelerometers; the main purpose of the shock test is to test the robustness of the materiel, test it by the destructive potential of the shock linked to the absolute maximum acceleration.

Apart from special indications, the shock response spectrum is therefore that of the absolute accelerations.

Note. In the case in which the mechanical system cannot be modeled by differential equations of the second degree with constant coefficients, the concept of shock response spectrum is not applicable (e.g., when the wave length of the shock is not great versus the dimensions of the materiel involved).

5.2 Characteristics of the Shock Response Spectrum

The shock response spectrum consists of:

- a primary positive spectrum and a primary negative spectrum: a point of maximum positive and negative responses which occur during the time of the pulse form of the shock (the, positive direction is that of the acceleration $\ddot{x}(t)$ of the shock).

- a residual positive spectrum and a residual negative spectrum: point of maximum positive and negative responses which occur after the pulse duration of the shock; as long as damping remains slight ($Q_n > 10$), these two spectra are equal in absolute value.

The maximax shock response spectrum is the envelope of the absolute maximum values of these four spectra.

Generally speaking the materiel is not symmetrical, its resistance depends on the direction of application of the shock. A shock corresponding to real data is not simple and the absolute maximum values of the response can correspond to values both negative and positive. For this reason the shock with the maximax response spectrum is applied along each direction.

Note: The shock response spectrum specified in control is therefore the maximax spectrum of the absolute accelerations.

The residual shock response spectrum of accelerations $A_R(\omega_n)$ is linked to the absolute value of the Fourier spectra of the shock $|F(\omega_n)|$, when the damping of the systems at one degree of freedom is zero.

If $|F(\omega_n)|$ is the Fourier transform modulus of the shock's acceleration time signal the relation is:

$$|F(\omega_n)| = \frac{A_R(\omega_n)}{\omega_n}$$

In this relation $|F(\omega_n|$ has the dimensions of a velocity, i.e., of an acceleration by rad/s.

The spectra of all the shocks with the same pulse form can be standardized in relation to the peak value of the acceleration A and to the duration D of the pulse: the coordinates scales are:

- ordinate a_{max} / A
- abscissa $f_n D$ or $2 \pi f_n D$

5.3 Description of Shock Response Spectra of Nominal Pulses

5.3.1 In the Case of Slight Damping ($Q_n > 10$)

Figure C5 shows the positive shock response spectra for the accelerations for the three types of pulse: final point sawtooth, half-sine, trapezoidal.

In the low frequency range up to $f_n D = 0.4$ the envelope is provided by the residual spectra and the response is in proportion to the velocity change of the pulse: meaning to say that the maximum response is more or less pulsive and approximately the same as that due to a Dirac pulse function whose velocity change is that of the area of the time form of the acceleration shock.

In the range of intermediate frequencies $0.4 < f_n < 1$.

The primary spectra offer differences in level which depend on the pulse rise time. The final point sawtooth which has the greatest rise time has the lowest response with a given pulse peak value. The trapezoidal pulse has the highest response owing to the very short rise time and the peak plateau.

For higher frequencies $f_n D > 5/2$.

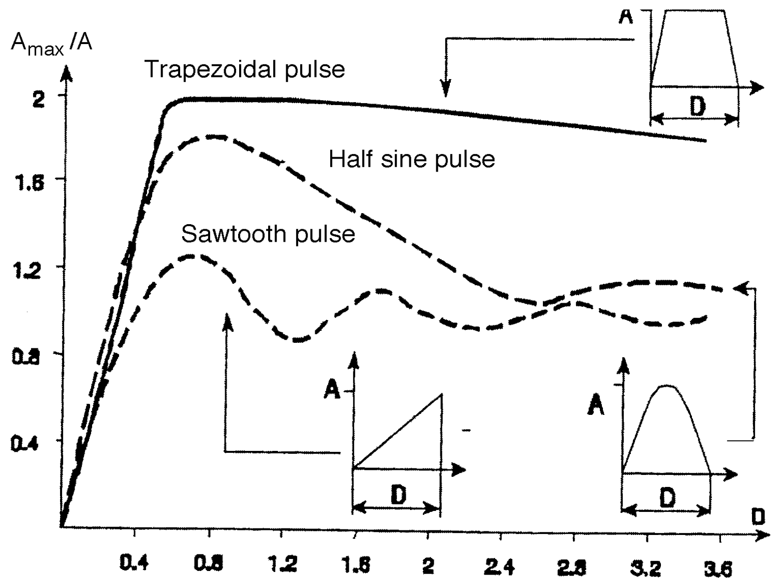

Figure C5. Positive SRS.

In all cases the response remains more or less constant: static area.

Figure C6 shows the primary (thick lines) and residual (fine lines) shock response spectra of the three types of pulses, and a nonzerodescent time for the sawtooth pulse.

The half-sine pulse has a practically nonexistent negative primary spectrum, in the same way as the trapezoidal pulse. This spectrum does not exist for the final point sawtooth pulse.

For the half-sine and trapezoidal pulses, only the positive residual spectra are shown in Figure C6. These spectra have periodically zero values due to the symmetry of the pulse wave. In return this drawback disappears with the sawtooth for which the positive residual spectrum is more or less merged for $f_n > 0.5$, with the primary spectrum. For a zero descent time, the negative residual spectrum is merged in absolute value with the positive residual spectrum. The effect of a nonzero descent time drops this spectrum below $f_nD > 5$ with alternating zero values.

The influence of the damping coefficient, slight with $Q_n > 10$, is more important on the negative spectra.

5.4 Effect of Ripples

Oscillatory systems with little damping are highly sensitive to ripples superimposed on the pulse.

To take an example the effects produced on the shock response spectrum of the half-sine are indicated in Figure C7.

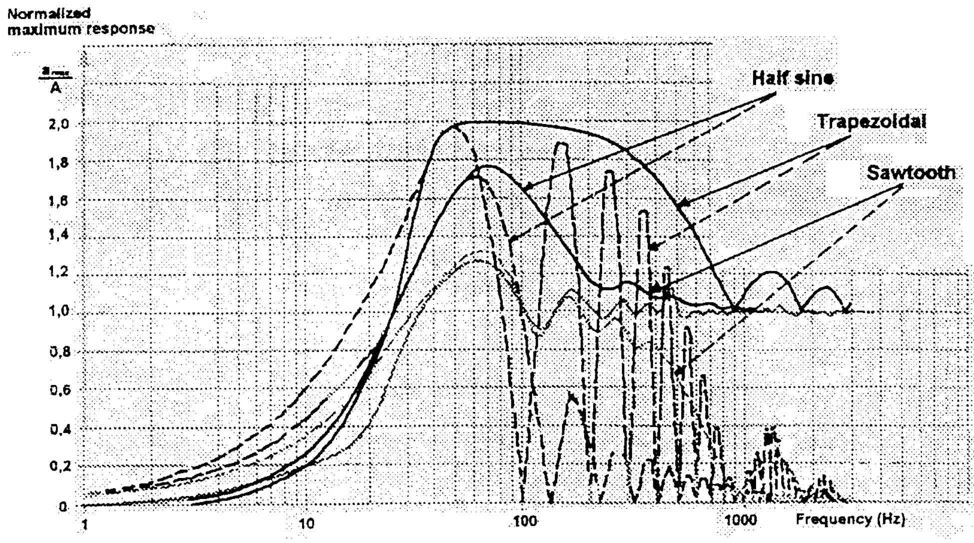

Figure C6. Primary (Thick Lines) and Residual (Fine Line) SRS.

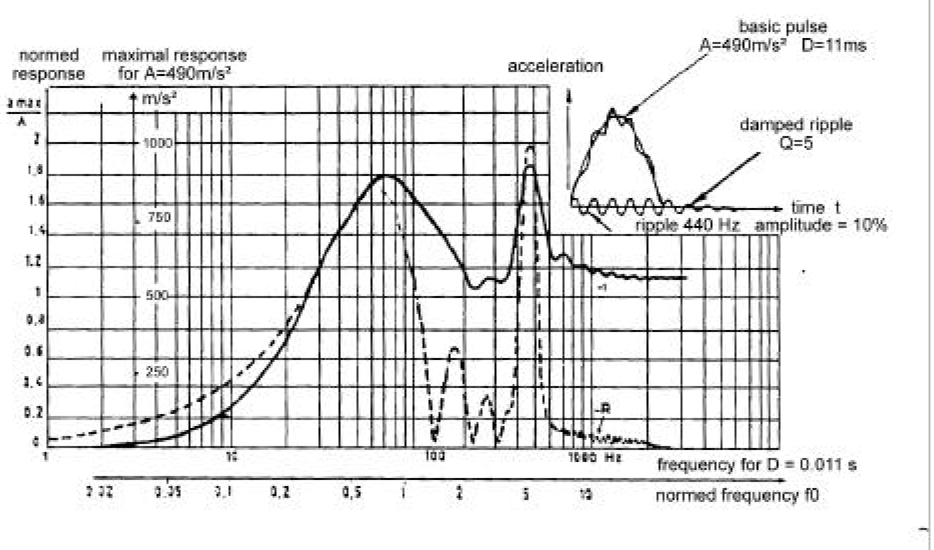

Figure C7. SRS of Half Sine Pulse With Ripple.

A ripple with an amplitude of 10 percent of that of the half-sine and frequency 460 Hz is superimposed on the pulse. The effect is considerable on the residual spectrum. Generally speaking as far as possible it is necessary to avoid ripples so as to preserve the reproducibility of the test.

The residual spectrum is very modified by weakly damped ripples which continue a long time after the nominal pulse.

5.4.1 Influence of Damping

5.5 Advantages of the Use of the Shock Response Spectrum Method in Comparison to Wave Form Method

a. easier representation of the real environment
b. independence of the temporal signal
c. aids assessment of the risk of dam age to the main modes
d. easier to specify (smoothing effect)
e. easier reproducibility
f. an infinity of temporal signals can be used in particular standard wave form (ex: 1/2 sine pre/post pulses)
g. for a simple model, calculation of the temporal response is easy(m aximum acceleration is easier to find)
h. allows comparison of the relative severities of different shocks synthesis of several shocks possible
i. tolerances easier to use than on the temporal signal

5.6 Limits of the Use of the Response Spectrum Method in Comparison to Wave Form Method

a. loss of the phase information and response modes recombination
b. loss of the time information, only with the temporal signal can we fully specify the shock limits and to analyze the good shock
c. because the shock is not fully specified, significant errors are possible
d. for one SRS we could find several shocks
e. in real systems, which are more complex than simple models, we have coupling, nonlinearities, n degrees of freedom (divergence in comparison with the 1 d.o.f)
f. SRS doesn't begin at f = 0 Hz and doesn't take into account the static aspect
g. propagation phenomenon which restrict the use when the size of structure is not greater than the wavelength in the materiel

5.7 Cautionary Notes on the Use of the Response Spectrum Method

a. it is difficult to determine the most suitable form of pre and/or post-pulses
b. excessive distortion of the control system generating a transient which is not of the impulsive type
c. a shock must not be replaced by a transient vibration unless its effects will be sufficiently s imilar

5.8 Use of Nominal Pulses

The terminal point sawtooth provides a better equivalence with the shock response spectrum but the effect of a nonnull time of return to zero is important on the negative spectrum. This is why this pulse must be applied in both directions.

The half-sine has a residual spectrum with periodical zero values, which can be a major drawback in certain cases.

The ripple effect can be considerable.

5.9 Systems With Several Degrees of Freedom

In order to be able to compute the shock response spectrum of a system with several degrees of freedom it is necessary to know how to schematize the action of the shock by a mate ix of generalized forces linked to the system's degrees of freedom. This schematization can be done in such a way as to ente r these generalized forces in the form of acceleration at the materiel's fastening points to the carrier for example equations (1) and (3) in paragraph 5.1 in matrix writing with n degrees of freedom.

In the case in which the mass of materiel is large and entails considerable coupling with the support structure, the system to be analyzed should include a part of the support. To undertake such computations it is indispensable that the vibration tests should have supplied the frequency transfer function of th e system from suitable excitation forces.

In most cases the specific modes of the system can be superimposed, decoupled and several shock response spectra can be computed for the damping values of the modes. With this procedure it is possible to enframe the specification of the test shock in such a way as not to overtest, when the real damping coefficient is less than the theoretical one employed, nor undertest in the opposite case.

6. GENERATION OF A SPECIFIED SHOCK

6.1 Shock Specified by Wave Form

6.1.1 Shock Machine

A specified wave form is obtained by adapting the programmer and the set up of the test item on the shock machine table. This adaptation depends on the type of machine used and is done experimentally with a ballasted mock-up of the test item.

6.1.2 Vibration Generators

6.1.2.1 Analog Assembly

The principle of control is provided by Figure C8.

The control chain includes:

- a programmable universal electrical pulse generator, with variable gain and adjustable pulse time, reproducing a pulse e(t) described by a set of time values

- a transfer function compensator; this (H_1) is adjustable by gain compensation devices in several frequency ranges and axial resonance frequency compensation devices

The transfer function (H_2 of the amplifier-vibration-test item assembly and control chain is measured by applying either sinusoidal sweeping, or a pulse, or a white noise with a sufficient number of statistical degrees of freedom.

The compensator is set by progressive amplitudes in order for the output signal s(t) to be:

$$s(t) = H_1 \cdot H_2\ e(t) = k\ e(t)$$

$$H_1 = \frac{k}{H_2}$$

An analog set up becomes difficult to use when the transfer function H_2 can no longer be simulated by that of a decoupled system. Digital control is then used.

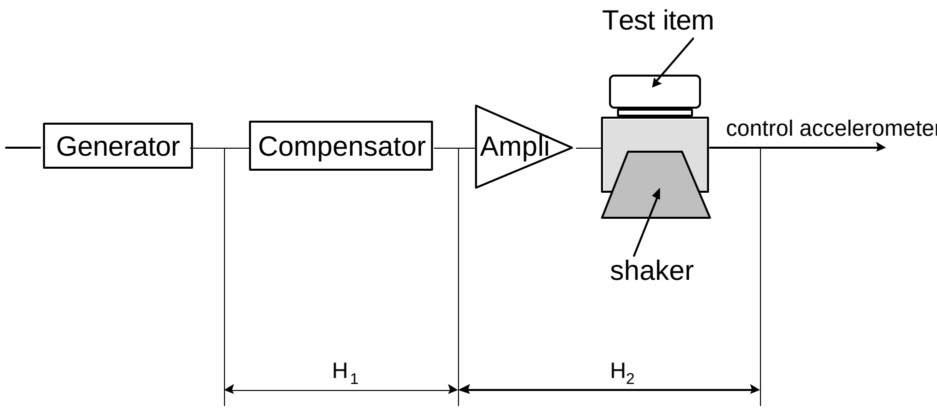

Figure C8. Analog Generation Set Up for the Wave Form Method.

6.1.2.2 Digital Set Up

The set up includes a universal computer programmed to adapt the reference input shock to the transfer function that may be symbolically written as $H_2(f) = s(f)/e(f)$ whose validity should be controlled by the coherence function between the output signal s(t) and the input signal e(t) if several pulses are averaged (otherwise the coherence function for one set of pulses is 1.0).

If:

$\overline{G_{11}(f)}$ direct Fourier transform of e(t)

$\overline{G_{22}(f)}$ direct Fourier transform of s(t)

$\overline{G_{12}(f)}$ cross Fourier transform between s(t) and e(t)

$\overline{G^*_{12}(f)}$ conjugate transform of $G_{12}(f)$

$$H_2(f) = \frac{\overline{G_{22}(f)}}{\overline{G_{11}(f)}}$$

$$\mu(f) = \frac{\overline{G^*_{12}(f)}.\overline{G_{12}(f)}}{\overline{G_{11}(f)}.\overline{G22(f)}}$$

where $\tilde{\tilde{G}}_{ij}$ represents an estimated average over several pulses.

The input signal is corrected by reverse Fourier transform at progressive amplitudes.

The correction loop can contain optimization programs depending on the specified wave form, and on the prepulse and post-pulse necessary to reduce the power required of the vibration generator while remaining within the specified tolerances of the wave form.

6.2 Specified Shock in the Form of a Shock Response Spectrum

6.2.1 Shock Machine

The only possibility is to generate the wave form whose shock response spectrum envelops as closely as possible, other the specified frequency range, the specified shock response spectrum. To do so certain rules based on the characteristics of the shock response spectrum are applied:

- the “static”' amplitude of the shock response spectrum at high frequencies provides the maximum acceleration of the wave form

- the pulse time of the wave form is provided by the abscissa of the first point which reaches the maximum acceleration of the wave form

The wave form obtainable closest to the one thus determined is adopted, preferably the terminal point sawtooth, whose shock response spectrum is best "filled" in each direction.

6.2.2 Vibration Generators

6.2.2.1 Analog Set Up

The principle of generation and control is shown in Figure C9.

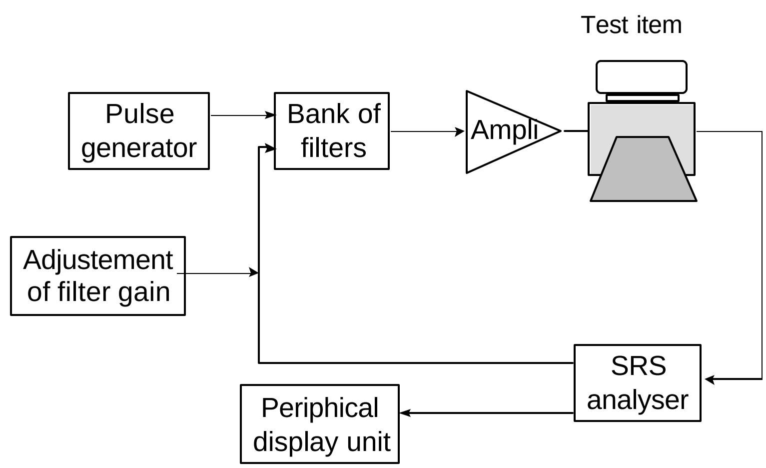

Figure C9. Analog Set Up for Shock Response Spectrum Generation.

6.2.2.2 Digital Set Up

Digital control consoles contain software which can synthesize a given shock response spectrum signal. The control console generates a set of transients, generally damped sinusoids of frequency f_n, logarithmic decrement n, and delay n, so that the shock response spectrum of each sinusoid coincides with that of the shock response spectrum specified at frequency f_n. The various parameters are adjusted contingent on the response spectrum obtained on output fom the generator system, test item and accelerometric control chain, progressively in amplitude.

This adjustment may require a prior approach through successive approximations, relatively long to adjust.

The system can contain dosed loop control possibl y with optimization

6.3 Test Setting Procedure

Figure C10 shows the diagram of the adjustment procedure required to generate the specified shock, either in wave form or in shock response spectrum, and depending on the operational area of the vibration generators amplifier (voltage e(t) and current i(t)).

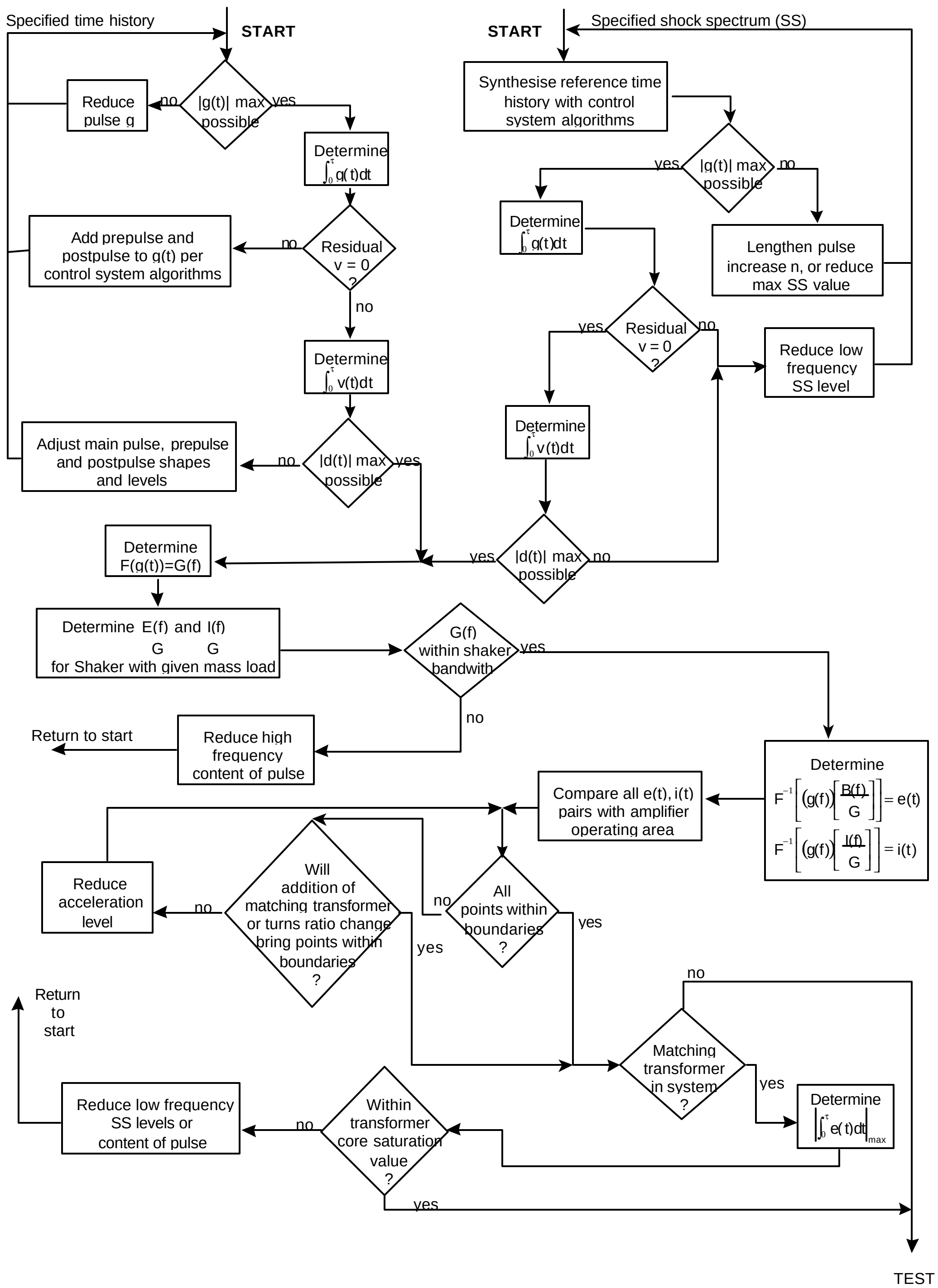

Figure C10. Procedure of adjustment diagram.

ANNEX D

STATISTICAL CONSIDERATIONS FOR DEVELOPING LIMITS ON PREDICTED AND PROCESSED DATA

(developed from MIL STD 810F)

1. SCOPE

1.1 Purpose

This Annex provides information relative to the statistical characterization of a set of data for the purpose of defining an envelope of the data set.

1.2 Application

Information in this Annex is generally applicable to frequency domain estimates that are either predicted based on given information or time domain environments processed in the frequency domain according to an appropriate technique i.e., for stationary random vibration the processing would be an ASD, for a very short transient the processing could be a SRS, ESD or FS. Given estimates in the frequency domain information in this Annex will allow the establishment of envelopes of the data in a statistically correct way.

2. DEVELOPMENT

2.1 Basic Estimate Assumptions

Combinations of prediction and measurement estimates may also be considered in the same manner. It is assumed here that uncertainty in individual measurement (processing error) does not effect the enveloping considerations. For measured field data digitally processed such that estimates of the SRS, ESD, FS or ASD are obtained for single sample records, it becomes useful to examine and summarize the overall statistics of “similar” estimates selected in a way so as to not bias the summary statistics. To ensure the estimates are not biased the measurement locations might be chosen randomly consistent with the measurement objectives. Similar estimated may be defined as (1) estimates at a single location on materiel that has been obtained from repeated testing under essentially identical experimental conditions, (2) estimates on a system that have been obtained from one test, where the estimates are taken (a) at several neighbouring locations displaying a degree of response homogeneity or (b) in “zones” i.e. points of similar response at varying locations, or (3) some combination of (1) and (2). It is assumed that there is a certain degree of homogeneity amongst the estimates across the frequency band of interest. This latter assumption generally requires that (1) the set of estimates for a given frequency have no significant "outliers" that can cause large variance estimates and (2) larger input stimulus to the system from which the measurements are taken implies larger estimate values.

2.2 Basic estimate summary pre-processing

There are two ways in which summary may be obtained. The first is to utilize an “enveloping” scheme on the basic estimates to arrive at a conservative estimate on the environment, and some qualitative estimate of the spread of basic estimates relative to this envelope. This procedure is dependent upon the judgment of the analyst and, in general, doe not provide consistent results among analysts. The second way is to combine the basic estimates in some statistically appropriate way and infer the statistical significance of the estimates based upon statistical distribution theory. Reference g summarizes the current state of knowledge relative to this approach and its relationship to enveloping.

In general, the estimates referred to and their statistics are related to the same frequency band over which the processing takes place. Unfortunately, for a given frequency band the statistics behind the overall set of estimates are not easily accessible because of the unknown distribution function of amplitudes for the frequency band of interest. In most cases the distribution function can be assumed to be normal if the individual estimates are transformed to a "normalizing" form by computing the logarithm to the base 10 of the estimate. For ESD, and FS estimates, the averaging of adjacent components (assumed to be statistically independent) increases the number of degree of freedom in the estimates while decreasing the frequency resolution with the possible introduction of statistical bias in the estimates. For ASD estimates, this also the case provided the bias error in the estimate is small, i.e., the resolution filter bandwidth is a very small fraction of the overall estimate bandwidth. For SRS estimates, because they are based on maximum response of a single-degree-of-freedom system as its natural frequency is varied, adjacent estimates tend to be statistically dependent and therefore not well smoothed with averaging filters unless the SRS is computed for very narrow frequency spacings. In such cases, smoothing of SRS estimates is better accomplished by reprocessing the original time history data at a broader natural frequency spacing, e.g., 1/6th octave as opposed to 1/12th octave. There is no apparent way to smooth dependent SRS estimates mathematically when reprocessing cannot be performed, and the acceptable alternative is some form of enveloping of the estimates. In any case, the larger the sample size the closer the logarithm transform of the estimates is to the normal distribution unless there is a measurement selection bias error in the experiment. Finally, it is important to note that generally the upper limit envelopes obtained in the paragraphs to follow, before application, are smoothed by straight line segments intersecting at spectrum "breakpoints". No guidance is provided in this Annex relative to this "smoothing" procedure e.g., whether estimates should be clipped or enveloped and the relationship of the bandwidth of the estimates to the degree of clipping, etc., except that such smoothing should be performed only by an experienced analyst. Reference g discusses this further.

2.3 Parametric Upper Limit Statistical Estimate Considerations.

In all the formulas for the estimate of the statistical upper limit of a set of N predictions or measurements,

$$\{X_1, X_2, ..., X_N\},$$

It is assumed that (1) the estimates will be logarithm transformed to bring the overall set of measurements closer to those sampled of a normal distribution and (2) the measurement selection bias error is negligible. Since the normal and “t” distribution are symmetric, the formulas below apply for the lower bound by changing the sign between the mean and the standard deviation quantity to minus. It is assumed here that all estimates are at a single frequency or for a single bandwidth, and that estimates among bandwidths are independent so that each bandwidth under consideration may be processed individually, and the results summarizes on one plot over the entire bandwidth as a function of frequency.

$$\text{For} \quad y_i = \log_{10}(x_i)$$

$$i = 1, 2, \ldots, N$$

Mean estimate for true mean, μ_y is given by

$$m_y = \frac{1}{N}\sum_{i=1}^{N} y_i$$

and the unbiased estimate of the standard deviation for the true standard deviation σ_y is given by

$$s_y = \sqrt{\frac{\sum_{i=1}^{N}\left(y_i - m_y\right)^2}{N-1}}$$

2.3.1 NCL - Upper normal confidence limit.

The upper confidence interval limit on the true mean μ_y with a confidence coefficient of $1 - \alpha$ (or confidence of $100\,(1-\alpha)\%$) is given by

$$NCL\,(N,\alpha) = 10^{m_y + \frac{S_y\, t_{N-1};\alpha}{\sqrt{N}}}$$

where $t_{N-1}; \alpha$ is the α percentage point of the Student t distribution with N-1 degrees of freedom. NCL is termed the upper $100(1-\alpha)\%$ confidence limit on the true mean of the population from which the sample $\{X_1, X_2, ..., X_N\}$ was taken. NCL is included here for reference purposes and generally is not useful for establishing upper limits unless N > 50.

2.3.2 Upper normal one-sided tolerance limit.

The upper normal one-sided tolerance limit on the proportion β of population values that will be exceeded with a confidence coefficient (γ) by at least by NTL(N, β, γ) is given by

$$NTL(N,\beta,\gamma) = 10^{m_y + s_y k_{N,\beta,\gamma}}$$

where $k_{N,\beta,\gamma}$ is the one-sided normal tolerance factor given in table D-1 for selected values of N, β and γ. NTL is termed the upper one-sided normal tolerance interval for which $100\,\beta\%$ of the values will lie below the limit with $100\,\gamma\%$ confidence. For $\beta = 0.95$ and $\gamma = 0.50$, this is referred to as the 95/50 limit.

The following table from reference g contains the k value N, β, γ. In general this method of estimation should not be used for small N with values of (β) and (γ) close to 1 since it is likely the assumption of the normality of the logarithm transform of the estimates will be violated. For N > 50, then NCL (N) = NTL (N, β, γ) for $a = 1 - \beta$ and $\gamma = 0.50$.

2.3.3 NPL - Upper normal prediction limit.

The upper normal prediction limit is the value of x (for the original data set) that will exceed the next predicted or measured value with confidence coefficient γ, and is given by

$$NPL(N,\gamma) = 10^{m_y + s_y\sqrt{1+\frac{1}{N}}\; t_{N-1;\alpha}}$$

where $\alpha = 1 - \gamma$. $t_{N-1;\alpha}$ is the "Student" variable with N-1 degrees of freedom at the $100\,\alpha = 100(1-\gamma)$ percentage point of the dstribution. This estimate, because of the assumptions behind its derivation, requires some careful interpretation relative to measurements made in a given location or over a zone.

TABLE D-1. Normal tolerance factors for upper tolerance limit.

N	g = 050			g = 0.90			g = 0.95		
	b = 0.90	b = 0.95	b = 0.99	b = 0.90	b = 0.95	b = 0.99	b = 0.90	b = 0.95	b = 0.99
3	1.50	1.94	2.76	4.26	5.31	7.34	6.16	7.66	10.55
4	1.42	1.83	2.60	3.19	3.96	5.44	4.16	5.14	7.04
5	1.38	1.78	2.53	2.74	3.40	4.67	3.41	4.20	5.74
6	1.36	1.75	2.48	2.49	3.09	4.24	3.01	3.71	5.06
7	1.35	1.73	2.46	2.33	2.89	3.97	2.76	3.40	4.64
8	1.34	1.72	2.44	2.22	2.76	3.78	2.58	3.19	4.35
9	1.33	1.71	2.42	2.13	2.65	3.64	2.45	3.03	4.14
10	1.32	1.70	2.41	2.06	2.57	3.53	1.36	2.91	3.98
12	1.32	1.69	2.40	1.97	2.45	3.37	2.21	2.74	3.75
14	1.31	1.68	2.39	1.90	2.36	3.26	2.11	2.61	3.58
16	1.31	1.68	2.38	1.84	2.30	3.17	2.03	2.52	3.46
18	1.30	1.67	2.37	1.80	2.25	3.11	1.97	2.45	3.37
20	1.30	1.67	2.37	1.76	2.21	3.05	1.93	2.40	3.30
25	1.30	1.67	2.36	1.70	2.13	2.95	1.84	2.29	3.16
30	1.29	1.66	2.35	1.66	2.08	2.88	1.78	2.22	3.06
35	1.29	1.66	2.35	1.62	2.04	2.83	1.73	2.17	2.99
40	1.29	1.66	2.35	1.60	2.01	2.79	1.70	2.13	2.94
50	1.29	1.65	2.34	1.56	1.96	2.74	1.65	2.06	2.86
¥	1.28	1.64	2.33	1.28	1.64	2.33	1.28	1.64	2.33

2.4 Nonparametric upper limit statistical estimate assumptions.

If there is some reason to believe that the data after it has been logarithm transformed will not be sufficiently normally distributed to apply the parametric limits defined above, then consideration must be given to nonparametric bounds i.e., bounds that are not dependent upon assumptions concerning the distribution of estimate values. In this case, there is no need to transform the data estimates. All of the assumptions concerning the selection of estimates are applicable for nonparametric estimates. With additional manipulation, lower limits may be computed using the information in Paragraphs 2.3.1., 2.3.2., and 2.3.3.

2.4.1 ENV - Upper limit.

The maximum envelope limit is determined by selecting the maximum estimate value in the data set.

$$ENV\ (N) = \max \{ X_1, X_2, \ldots\ldots X_N \}$$

The main disadvantage of this estimate is that the distributional properties of this estimate set are neglected so that no probability of exceedance of this value is specified. In the case of outliers in the estimate set, ENV (N) may be far too conservative. ENV (N) is also sensitive to the bandwidth of the estimates.

2.4.2 DFL - Upper distribution-free tolerance limit.

The distribution-free tolerance limit that utilizes the original untransformed sample values is defined to be the upper limit for which the fraction β of all sample values will be less than the maximum predicted or measured value with a confidence coefficient of γ. This is based on order statistic considerations.

$$DFL(N, \beta, \gamma) = x_{max}; \gamma = 1 - \beta^N$$

where x_{max} is the maximum value of the set of data; β is the fractional proportion below x_{max}, and γ is the confidence coefficient. Given N, β and γ are not independently selectable. That is:

a. Given N and assuming a value of β, $0 \le B \le 1$, the confidence coefficient can be determined,

b. Given N and γ, the proportion β can be determined,

c. Given β and γ, the number of samples can be determined such that the proportion and confidence can be satisfied (for statistical experiment design).

DFL(N, β, γ) may not be meaningful for small samples of data $N \le 13$ and comparatively large $\beta > 0.95$. DFL(N, β, γ) is sensitive to the estimate bandwidth.

2.4.3 ETL - Upper empirical tolerance limit.

The empirical tolerance limit uses the original untransformed sample values and assumes the predicted or measured estimate set is composed of N measurement point over M frequency resolution bandwidths for a total of NM estimate values. That is :

$$\{x_{11}, x_{12}, ..., x_{1M}, x_{21}, x_{22}, ..., x_{2M}, x_{N1}, x_{N2}, ..., x_{NM}\}$$

where m_j is the average at the j^{th} frequency bandwidth over all N measurement points.

$$m_j = \frac{1}{N}\sum_{i=1}^{N} x_{i_j} \quad j = 1,2,...,M$$

m_j is used to construct an estimate set normalized over individual frequency resolution bandwidth. That is:

$$\{u_{11}, u_{12}, ..., u_{1M}, u_{21}, u_{22}, ..., u_{2M}, u_{N1}, u_{N2}, ..., u_{NM}\}$$

$$\text{where}: u_{ij} = \frac{x_{i_j}}{m_j} \quad i = 1,2,...,N;\ j = 1,2,...,M$$

The normalized estimate set {u} is ordered from smallest to largest and

$u_\beta = u_{(k)}$ where $u_{(k)}$ is the k^{th} ordered element of set {u} for $0 < \beta = \frac{k}{MN} \le 1$ is defined.

For each frequency or frequency band, then

$$ETL(\beta) = \mu_\beta m_j = x_{\beta_j} \qquad j = 1, 2, ..., M$$

Using m_j implies that the value of ETL(β) at j exceeds β% of the values with 50% confidence. If a value other than m_j is selected, the confidence level may increase. It is important that the set of estimates be homogeneous to use this limit, i.e., they have about the same spread in all frequency bands. In general, the number of measurement points, N, should be greater than 10 to apply this limit.

3. RECOMMENDED PROCEDURES

3.1 Recommended statistical procedures for upper limit estimates.

Reference g provides a discussion of the advantages and disadvantages of estimate upper limits. The guidelines in this reference, will be recommended here. In all cases, the data should be carefully plotted with a clear indication of the method of establishing the upper limit and the assumptions behind the method utilized.

a. When N is sufficiently large i.e., N > 6 establish the upper limit by using the expression for the DFL for a selected $\beta \geq 0.90$ such that $\gamma \geq 0.50$.

b. When N is not sufficiently large to meet the criterion in (1), then establish the upper limit by using the expression for the NTL …Select β and $\gamma \geq 0.50$. Variation in β will determine the degree of conservativeness of the upper limit.

c. For N > 10 and a confidence coefficient of 0.50 is acceptable then the upper limit established on the basis of ETL may be substituted for the upper limit established by DFL or NTL. It is important when using ETL to examine and confirm the homogeneity of the estimates over the frequency band.

3.2 Uncertainty factors

Uncertainty factors may be added to the resulting envelopes if confidence in the data is low or the data set is small. Factors on the order of 3 dB to 6 dB may be added. Reference g recommends a 5.8 dB uncertainty factor based on flight-to-flight and point-to-point uncertainties be added to captive carry flight measured data to determine a maximum expected environment using a normal tolerance limit. It is important that all uncertainties be clearly defined and that uncertainties are not superimposed upon estimates that already account for uncertainties.

ANNEX E

REFERENCE/RELATED DOCUMENTS

a. Harris, C., and C. E. Crede, eds. Shock and Vibration Handbook, 2nd Edition, NY, McGraw-Hill, 1976.

b. Gaberson, H. A. and R. H. Chalmers. Model Velocity as a Criterion of Shock Severity, Shock and Vibration Bulletin 40, Pt. 2, (1969) 31-49.

c. ANSI/ASTM D3332-77, Standard Methods for Fragility of Products Using Machines. 1977.

d. Conover, W.J., practical Nonparametric Statistics. New York; Wiley, 1971, Chapter 3.

e. Piersol, A.G., Analysis of Harpoon Missile Structural Response to Aircraft Launches, Landings and Captive Flight and Gunfire. Naval Weapons Center Report #NWC TP 58890. January 1977.

f. Handbook for Dynamic Data Acquisition and Analysis, IES-RP-DTE012.1, Institute of Environmental Sciences, Mount Prospect, IL.

g. Piersol, Allan G., Determination of Maximum Structural Responses From Predictions or Measurements at Selected Points, Proceedings of the 65th Shock and Vibration Symposium, Volume I, SAVIAC, 1994.

h. Bendat, J. S., and A. G. Piersol, Random Data : Analysis and Measurement Procedures, John Wiley & Sons Inc., New York 1986

i. Schock, R. W. and W. E. Paulson, TRANSPORTATION A Survey of Shock and Vibration environments in the Four Major Modes of Transportation, Shock and Vibration Bulletin #35, Part 5, February 1966.

j. Ostrem, F. E., TRANSPORTATION AND PACKAGING A Survey of the Transportation Shock and Vibration Input to Cargo, Shock and Vibration Bulletin #42, Part 1, January 1972.

METHOD 418

MOTION PLATFORM

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ANNEX A

INITIAL TEST SEVERITIES

METHOD 418

MOTION PLATFORM

1 SCOPE

1.1 Purpose

The purpose of this test method is to replicate the motion platform conditions, incurred by systems, subsystems and units (hereafter called materiel) during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist at the specified motion platform environment without unacceptable degradation of its functional and/or structural performance.

1.3 Limitations

This test is not intended to represent any motion of the platform other than rigid body motion

2 GUIDANCE

2.1 Effects of environment

The following list is not intended to be all inclusive but provides examples of problems encountered when materiel is exposed to motion platform :

1) Structural deformation,
2) Cracking and rupturing,
3) Loosening of fasteners,
4) Loosening of parts of components.

2.2 Use of measured data

Where practicable, measured data should be used to develop test levels.

2.3 Sequence

The order of application of test should be considered and made compatible with the Service Life Cycle Environmental Profiles.

2.4 Choice of test procedures

There is only one test procedure (see par 5.4)

2.5 Types of motion

Unless otherwise specified, the motion should be sinusoidal. However, if measured data are available, they can be simulated.

2.6 Control strategy

This motion can be controlled with an angular sensor, or It is possible to use a linear sensor fixed to the table. In the latter case, it is necessary to make a correction between linear and angular motion.

3 SEVERITIES

When practicable, test levels and durations will be established using projected service use profiles and other relevant available data. When data are not available, initial test severities are to be found in Annex A. These severities should be use in conjunction with the appropriate information given in AECTP 200. These severities should be considered as initial values until measured data is obtained. Where necessary, these severities can be supplemented at a later stage by data acquired directly from an environmental measurement programme.

4 INFORMATIONS TO BE SPECIFIED IN THE TEST INSTRUCTION

4.1 Compulsory

- the identification of test item,
- the definition of test item,
- the definition of test severity,
- the orientation of the test item in relation of the test axes,
- operation checks : initial, final,
- details required to perform the test,
- the indication of failure criteria.

4.2 If required

- tolerances, if different from para 5.3,
- the specific features of the test assembly

5 TEST CONDITIONS

5.1 Types of motion

Four motions are defined :

- Roll is the oscillatory motion of a ship about the longitudinal axis (x).
- Pitch is the oscillatory motion of a ship about the transverse axis (y).
- Yaw is the oscillatory motion of a ship about the vertical axis (z).
- Heave is the oscillatory motion of a ship in the vertical axis (z).

5.2 Test Facility

The test facility is typically a large table which can oscillate about a horizontal axis.

Two kind of apparatus are used :

- an horizontal table coupled, at each end, with two or more vertical hydraulic actuators. This method necessitates a control system to generate the actuator motions such that the centre axis of the table is motionless. As an alternative, the control system can generate motion where the centre axis of the table does not remain motionless. This alternative allows for the table to generate heave motion.
- A horizontal table with bearings forming a fixed horizontal hinge line. The table oscillate by use of one or several hydraulic actuators. This method does not considers heave motion.

5.3 Tolerancies

a) frequencies :

(1) ± 0.05 Hz from 0 to 0.5 Hz

(2) ± 10% from 0.5 Hz to 5 Hz

b) angular displacement :

(1) ± 15% at the control signal

5.4 Procedure

Step 1. Pre-condition the test item, if applicable,

Step 2. Implement control strategy, including control and monitoring points,

Step 3. Undertake initial operational checks,

Step 4. Apply specified motion , and carry out required operation and functional checks,

Step 5. Undertake final operation checks,

Step 6. Repeat steps 1 to 5 for the other specified axes,

Step 7. Record the information required

If the service orientation is unknown on board, the materiel will be tested in all three major axes.

The test programme will specify if test item must function or not.

6 FAILURE CRITERIA

The test item shall meet all the appropriate specification requirements following the test.

ANNEX A

INITIAL TEST SEVERITIES

The materiel will be subject to :

- roll motions and
- pitch motions

The initial severities for a sea state 5/6 will be :

	Roll		**Pitch**		**Test duration**
	Frequency (Hz)	**Angle** (degrees)	**Frequency** (Hz)	**Angle** (degrees)	
Aircraft carrier :	0.065	20	0.143	5	30 mn/axis
Frigate :	0.091	12	0.196	2.9	
Submarine :	0.143	25	0.100	10	

Note : Test severities are not quoted for yaw and heave motions because Service levels are usually low.